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This special number of the *New Zealand Journal of Geology and Geophysics* marks the centenary of the field work in New Zealand of Ferdinand von Hochstetter, geologist attached to the expedition round the world of the Austrian Frigate *Novara* in 1857-1859. The *Novara* visited Auckland from 22 December 1858 till 8 February 1859, during which period Hochstetter made a report to the Colonial Government on the Drury Coalfield in the Auckland Province.

His work greatly impressed the Auckland Provincial Government and, at the invitation of the Provincial Governments of Auckland and Nelson, he remained in New Zealand until 2 October 1859.

During this time, he explored a large part of south Auckland Province from Auckland Isthmus south to Taupo, and the more accessible parts of Nelson, as a basis for topographical and geological maps.

His final report, incorporating all that was then known of the subject, was published in 1864 under the title "Geologie von Neu-Seeland".

Hochstetter's field work, which was the first major contribution to the geology of this country, established the valuable tradition of regional geological mapping associated with careful paleontological studies that has provided the basis for a century of progress in geological research.

In the early years of their development, few small countries have had the services of a man of such outstanding ability, and, in marking this centenary, New Zealand geologists pay tribute to one of their great pioneers.

VERZEICHNIS DER IN DER GEOL.-PALAEONTOL. ABTEILUNG DES NATURHISTORISCHEN MUSEUMS WIEN, AUSTRIA, AUFBEWAHRTEN TYPEN UND ABBILDUNGSORIGINALE AUS DEN AUFSAMMLUNGEN DER NOVARA-EXPEDITION

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(Mit einem Anhang von C. A. Fleming und N. de B. Hornibrook)

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Die 1857-1859 von der österreichischen Novara-Expedition in Neuseeland, Java und auf den Nikobaren aufgesammelten Fossilien wurden von G. Jaeger, F. Karrer, A. E. Reuss, C. Schwager, G. Stache, F. Stoliczka, Fr. Unger, und K. A. Zittel bearbeitet; die Ergebnisse wurden im Geologischen Teil (Band 1, 2. Abteilung und Band 2, 2. Abteilung und Band 2, 2. Abteilung) des von der kaiserlichen Akademie der Wissenschaften zu Wien herausgegebenen Werkes "Reise der Österreichischen Fregatte Novara um die Erde in den Jahren 1857, 1858, 1859 unter den Befehlen des Commodore B. von Wüllerstorf-Urbair" (Wien 1864 und 1866) veröffentlicht.

Nach dem Willen Ferdinand von Hochstetters (1866, S. VI) solten sämtliche Originale der beschriebenen Fossilien dem damaligen kaiserlichen Hof-Mineralienkabinett (und jetzigen Naturhistorischen Museum) einverleibt werden, während die Doubletten an andere wissenschaftliche Sammlungen der österreichisch-ungarischen Monarchie verteilt werden sollten. Da die durch die Novara-Expedition aufgesammelten Fossilien für die paläontologische Kenntnis Neuseelands von grundlegender Bedeutung sind, erschien es wünschenswert, einen Überblick über die noch vorhandenen Originalmaterialien zu geben. Wie die Durchsicht der systematisch-paläontologischen Sammlung und der Suiten-Sammlung der Geol.-Paläontologischen Abteilung gezeigt hat, ist nur ein Teil der im Novara-Werk bearbeiteten Fossilien an das

N.Z. J. Geol. Geophys. 2 : 826-43.

STATEMENT CONCERNING THE TYPES AND FIGURED ORIGINALS FROM THE COLLECTIONS OF THE NOVARA EXPEDITION IN THE CUSTODY OF THE GEOLOGICAL-PALEONTOLOGICAL SECTION OF THE MUSEUM OF NATURAL HISTORY, VIENNA, AUSTRIA

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(With an Appendix by C. A. Fleming and N. de B. Hornibrook)

Summary

The types and figured originals of fossils collected by the Novara Expedition, preserved in the Natural History Museum, Vienna, are tabulated, and missing specimens listed. Types described by Jaeger, Karrer, Reuss, Stache, and Zittel are in the Museum, but those described by Schwager, Stoliczka, and Unger are missing.

Notes on the localities of New Zealand fossils collected by the Novara Expedition are given in an appendix.

Fossils collected by the Austrian Novara Expedition during 1857-1859 from New Zealand, Java, and the Nicobar Islands were investigated by G. Jaeger, F. Karrer, A. E. Reuss, C. Schwager, G. Stache, F. Stoliczka, Fr. Unger, and K. A. Zittel: the results were published by the Imperial Academy of Science, Vienna, in the geological part of the "Reise der Österreichischen Fregatte Novara um die Erde in den Jahren 1857, 1858, 1859 unter den Befehlen des Commodore B. von Wüllerstorm-Urbair", Vienna 1864, 1866 (Vol. I, Sect. 2; Vol. II, Sect. 2).

In accordance with the wish of Ferdinand von Hochstetter (1866, p. vi), all the originals of described fossils had to be incorporated in the Mineral Collections of the then Imperial Court (now the Museum of Natural History), while the duplicates had to be divided amongst the other scientific collections of the Austrian-Hungarian Monarchy. As the fossils collected by the Novara Expedition are of fundamental importance for the paleontological knowledge of New Zealand, it appears desirable to give a review of the original material still available. An inspection of the systematic-paleontological collection and of the rock-sequence collection of the Geological-Paleontological Department has shown that only part of the investigated Novara fossils fell to the

Wiener Naturhistorische Museum gekommen. Es sind dies die Belegstücke zu den Arbeiten von G. Jaeger 1864, F. Karrer 1864, A. E. Reuss 1866, G. Stache 1864, und K. A. Zittel 1864.

Es fehlen die von Schwager 1866 von den Nikobaren beschriebenen Foraminiferen, die von Stoliczka 1864 untersuchten Bryozoen aus dem Tertiär der Orakei Bay bei Auckland und die von Unger bekanntgemachten Pflanzenreste. Das Belegmaterial zu den Bryozoen-Studien Stoliczkas befindet sich möglicherweise in der Sammlung des Geological Survey of India in Calcutta, da Stoliczka 1862 bei seiner Reise nach Indien—von der er nicht mehr nach Europa zurückkehrte—die Fossilien mitnahm (Stoliczka 1864, S. 90). Wie eine Rückfrage bei Frau Dr. Wiesböck ergab, besitzt die Geologische Bundesanstalt in Wien keine Fossilmaterialien aus den Aufsammlungen der Novara-Expedition. Diese Aussage kann jedoch nicht als verbindlich angesehen werden, da ein Grossteil der Bestände der Geol. Bundesanstalt während des 2. Weltkrieges bei Bombenangriffen in Unordnung geraten und heute noch nicht völlig zugänglich ist. Des Naturhistorische Museum Wien blieb von Kriesgsschäden verschont, ein Grossteil der Bestände war verlagert. Einzelne Lücken unter den Novara-Fossilien dürften auf diese kriegsbedingten Umstellungen zurückzuführen sein; jedoch besteht auch hier die Möglichkeit, dass das eine oder andere Stück—an falscher Stelle eingeordnet—noch zum Vorschein kommt.

Soweit es sich um Typus-Originale handelt, befinden sich die Fossilien in der Typen-Sammlung der Geol.-Paläontol. Abteilung. Die Abbildungs- und Beschreibungs-Originale werden in einer selbständigen Suite "Novara-Expedition" aufbewahrt. In allgemeinen sind die Fossilien gut erhalten. Die ursprünglich in Fläschchen aufbewahrten Foraminiferen wurden in Zellen umgefüllt, die übrigen Fossilien am Stück beschriftet, sodass keine Verwechslung oder Vertauschung erfolgen kann.

In der folgenden Liste wurden (nach Mayr, Linsley, and Usinger 1953, S. 239) unterschieden: Holotypus—das vom Autor als Typus oder typisch bezeichnete Exemplar (Holotypus designatus, HT d.); das zur Zeit der Originalbeschreibung einzig bekannte Exemplar (Holotypus monotypicus, HT m.). Paratypus—ein vom Holotypus unterschiedenes Exemplar, das vom Autor untersucht wurde und als Grundlage der Originalbeschreibung verwendet wurde, abgekürzt PT. Syntypus (ST)—eines von mehreren Exemplaren, das dem Autor als Grundlage zur Schaffung der Art diente, wenn kein Exemplar als Holotypus bezeichnet wurde. Bei den von Stache beschriebenen Foraminiferen ist für die meisten Arten nur ein Exemplar abgebildet und vom Autor näher untersucht worden—obwohl, wie aus den Angaben "häufig", "selten", etc. hervorgeht, mehrere Exemplare vorhanden gewesen sein müssen, die aber möglicherweise nicht deponiert wurden. In diesen Fällen wird das einzig vorhandene Exemplar als HT m. bezeichnet.

Museum of Natural History in Vienna. These are the types from the work by G. Jaeger 1864, F. Karrer 1864, A. E. Reuss 1866, G. Stache 1864, and K. A. Zittel 1864.

The Foraminifera described by Schwager 1866 from the Nicobar Islands, the Bryozoa investigated by Stoliczka 1864 from the Tertiary of Orakei Bay, Auckland, and the plant remains reported by Unger are missing. The types of Stoliczka's Bryozoa may perhaps be in the collection of the Geological Survey of India, Calcutta, as Stoliczka took these fossils with him on his trip to India from where he did not return to Europe (Stoliczka, 1864, p. 90). An inquiry with Dr Wiesböck revealed that the Austrian Geological Survey is not in the possession of fossil material from the collections of the Novara Expedition. This communication, however, cannot be taken as definite proof, as a major part of the collections of the Geological Survey was disorganized through air raids in the Second World War and is not yet entirely available today. The Museum of Natural History in Vienna did not suffer any war damage; most of the collections were, however, placed elsewhere. A few gaps among the Novara fossils may have been caused by these war-time shifts; however, the possibility exists that some parts of the collection, accidentally misplaced, may still come to light.

As far as the original types are concerned, the fossils are in the type collection of the Geological-Paleontological Department. The figured and the described originals have been lodged in a separate "Novara Expedition" unit. The fossils are, generally speaking, well preserved. The Foraminifera, which were originally stored in small bottles, have been transferred to pill boxes, the rest bear labels, so that no misplacing can occur.

In the list below, the following terms have been used (after Mayr, Linsley, and Usinger, 1953, p. 239): Holotype—the specimen designated by the author as type or typical (Holotypus designatus, HT d.); the only known specimen at its time of description (Holotypus monotypicus, HT m.). Paratypus—a specimen other than the holotype, but used by the author in establishing the holotype, abbreviated PT. Syntypus (ST)—one of several specimens used by the author in establishing the species, when no specimen was designated as holotype. For most of the foraminiferal species described by Stache, only one specimen was figured and described by that author, although, as appears from the remarks "common" and "rare", etc., several specimens must have been available, although possibly not deposited. In these cases the only available specimen has been designated HT m.

I. G. Stache, 1864: Die Foraminiferen der tertiären Mergel des Whaingaroa-Hafens (Provinz Auckland). *Novara-Exped. Geol. Theil, 1 (2)* : 161-304, pl. 21-24.

Fundpunkt: Umgebung des Hafens von Whaingaroa, Westküste der Provinz Auckland, Neuseeland.

Stratigraphie: Tertiär.

Name	Seite	pl.	fig.	Zahl der Exempl.	Typus	Aqu-Nr.
Bulimina aperta Stache	266	24	15	1	HT m.	1866 VIII 102
——— *ovata* d'Orb	266	24	14	1	Abb. O.	1866 VIII 101
——— *propinqua* Stache	267	24	16	1	HT m.	1866 VIII 103
Clavulina antipodum Stache	167	21	3-8	6	ST	1866 VIII 2 und 3
——— *robusta* Stache var. a	169	21	9-10	2	ST	1866 VIII 4
Cornuspira archimedis Stache	180	22	1	1	HT m.	1866 VIII 15
——— *elliptica* Stache	181	22	2	1	HT m.	1866 VIII 16
Cristellaria bucculenta Stache	238	23	17	1	HT m.	1866 VIII 75
——— *bufo* Stache	239	23	18	1	HT m.	1866 VIII 76
——— *callifera* Stache	236	23	15	1	HT m.	1866 VIII 73
——— *cilo* Stache	234	23	13	1	HT m.	1866 VIII 71
——— *colorata* Stache	229	23	9	1	HT m.	1866 VIII 67
——— *duracina* Stache	237	23	16	1	HT m.	1866 VIII 74
——— *falcifer* Stache	240	23	19	1	HT m.	1866 VIII 77
——— *glaucina* Stache	241	23	20	1	HT m.	1866 VIII 78
——— *intermedia* d'Orb. var. *whaingaroica*	242	23	21	1	HT m.	1866 VIII 79
——— *lactea* Stache	235	23	15	1	HT m.	1866 VIII 72
——— *larva* Stache	232	23	11	1	HT m.	1866 VIII 69
——— *rotula* Stache	233	23	12	1	HT m.	1866 VIII 70
Dentalina deformis Stache	205	22	32	1	HT m.	1866 VIII 40
——— *marginata* Stache	207	22	35	1	HT m.	1866 VIII 41
——— *obliquesuturata* Stache	207	22	36	1	HT m.	1866 VIII 42
——— *pomuligera* Stache	204	22	31	1	HT m.	1866 VIII 39
——— *scarificata* Stache	209	22	40	1	HT m.	1866 VIII 45
——— *striatissima* Stache	208	22	38	1	HT m.	1866 VIII 43

——— *soluta* Reuss	203	22	29	4	Abb. Orig.	1866 VIII 38
——— *verticalis* Stache	202	22	28	1	HT m.	1866 VIII 37
——— sp. indet.	209	22	39	1	Abb. Orig.	1866 VIII 44
Frondicularia whaingaroica Stache	210	22	43	1	HT m.	1866 VIII 47
Gaudryina capitata Stache	176	21	15	1	HT m.	1866 VIII 10
——— *insecta* Stache	177	21	18	1	HT m.	1866 VIII 11
——— *megastoma* Stache	173	21	13	1	HT m.	1866 VIII 8
——— *novo-zelandica* Stache	174	21	14	1	HT m.	1866 VIII 9
——— *obliquata* Stache	172	21	12	1	HT m.	1866 VIII 7
——— *reussi* Stache	171	21	11	1	HT m.	1866 VIII 6
Glandulina annulata Stache	184	22	6	1	HT m.	1866 VIII 18
——— *aperta* Stache	188	22	11	1	HT m.	1866 VIII 23
——— *erecta* Stache	189	22	12	1	HT m.	1866 VIII 24
——— *napaeformis* Stache	186	22	9	1	HT m.	1866 VIII 20
——— *rimosa* Stache	187	22	10	1	HT m.	1866 VIII 22
——— *subovata* Stache	185	22	7	1	HT m.	1866 VIII 19
——— *symmetrica* Stache	187	22	9	1	HT m.	1866 VIII 21
Globigerina bulloides d'Orb.	286	24	35	3	Abb. Orig.	1866 VIII 116
——— *reticulata* Stache	287	24	37	24	ST	1866 VIII 117
Guttulina fissurata Stache	263	24	10	1	HT m.	1866 VIII 100
Haplophragmium incisum Stache	165	21	1	1	HT m.	1866 VIII 1
Hemicristellaria excavata Stache	224	23	3	1	HT m.	1866 VIII 62
——— *infrapapillata* Stache	224	23	4	1	HT m.	1866 VIII 63
——— *procera* Stache	222	23	1	1	HT m.	1866 VIII 60
Hemirobulina arcuatula Stache	227	23	6	1	HT m.	1866 VIII 64
——— *compressa* Stache	228	23	7	1	HT m.	1866 VIII 66
——— *galeola* Stache	229	23	8	1	HT m.	1866 VIII 65
Lingulina decipiens Stache	193	22	17	1	HT m.	1866 VIII 29
——— *glans* Stache	191	22	14	1	HT m.	1866 VIII 26
——— *intustriata* Stache	190	22	13	1	HT m.	1866 VIII 25
——— *propinqua* Stache	191	22	15	1	HT m.	1866 VIII 27
——— *rimosa* Stache	192	22	16	1	HT m.	1866 VIII 28
Marginulina angistoma Stache	213	22	46	1	HT m.	1866 VIII 50
——— *apiculifera* Stache	216	22	49	1	HT m.	1866 VIII 53
——— *asprocostulata* Stache	219	22	53	1	HT m.	1866 VIII 57
——— *cristellata* Stache	212	22	44	1	HT m.	1866 VIII 48
——— *duracina* Stache	211	22	42	1	HT m.	1866 VIII 46
——— *elatissima* Stache	219	22	54	1	HT m.	1866 VIII 58

Name	Seite	pl.	fig.	Zahl der Exempl.	Typus	Aqu.-Nr.
Marginulina hochstetteri Stache	221	22	55	1	HT m.	1866 VIII 59
——— *interrupta* Stache	212	22	45	1	HT m.	1866 VIII 49
——— *mucronulata* Stache	215	22	48	1	HT m.	1866 VIII 52
——— *opaca* Stache	214	22	47	1	HT m.	1866 VIII 51
——— *pellucida* Stache	217	22	51	1	HT m.	1866 VIII 55
——— *spinulosa* Stache	216	22	50	1	HT m.	1866 VIII 54
——— *tricuspis* Stache	218	22	52	1	HT m.	1866 VIII 56
Nodosaria antipodum Stache	194	22	19	1	HT m.	1866 VIII 30
——— *callosa* Stache	197	22	23	1	HT m.	1866 VIII 33
——— *obliquecostata* Stache	197	22	24	1	HT m.	1866 VIII 34
——— *striatissima* Stache	198	22	25	1	HT m.	1866 VIII 35
——— *subrhombica* Stache	201	22	26	1	HT m.	1866 VIII 36
——— *substrigata* Stache	196	22	22	1	HT m.	1866 VIII 32
——— sp. indet.	194	22	20	1	Abb. Orig.	1866 VIII 31
Plecanium eurystoma Stache	179	21	19	3	ST	1866 VIII 14
——— *granosissimum* Stache	179	21	18	1	HT m.	1866 VIII 13
——— *karreri* Stache	178	21	17	1	HT m.	1866 VIII 12
Polymorphina cognata Stache	257	21	3	1	HT m.	1866 VIII 93
——— *contorta* Stache	257	21	4	1	HT m.	1866 VIII 94
——— *dispar* Stache	261	21	8	1	HT m.	1866 VIII 98
——— *gigantea* Stache	262	21	8	1	HT m.	1866 VIII 99
——— *incavata* Stache	260	21	7	1	HT m.	1866 VIII 97
——— *lingulata* Stache	255	21	1	1	HT m.	1866 VIII 91
——— *marsupium* Stache	258	21	5	1	HT m.	1866 VIII 95
——— *pernaeformis* Stache	256	21	2	1	HT m.	1866 VIII 92
——— *sacculus* Stache	259	21	2	1	HT m.	1866 VIII 96
Robulina coronalunae Stache	250	23	29	2	ST	1866 VIII 86
——— *cultrata* d'Orb. var. *antipodum* Stache	251	23	30	1	HT m.	1866 VIII 87
——— *foliata* Stache	245	23	24	1	HT m.	1866 VIII 81
——— *halophora* Stache	248	23	28	1	HT m.	1866 VIII 85
——— *incrustata* Stache	254	23	33	1	HT m.	1866 VIII 90
——— *lenticula* Stache	246	23	25	1	HT m.	1866 VIII 82

Robulina loculosa Stache	244	23	23	1	HT m.	1866 VIII 80
——— *oculus* Stache	247	23	27	1	HT m.	1866 VIII 84
——— *pseudo-calcarata* Stache	252	23	31	1	HT m.	1866 VIII 88
——— *pusilla* Stache	247	23	26	1	HT m.	1866 VIII 83
——— *taettowata* Stache	252	23	32	1	HT m.	1866 VIII 89
Rosalina fasciata Stache	281	24	**31**	1	HT m.	1866 VIII 113
——— *maorica* Stache	282	24	32	2	ST	1866 VIII 114
——— *orbiculus* Stache	285	24	34	1	HT m.	1866 VIII 115
——— *thiara* Stache	279	24	29 30	2	ST	1866 VIII 112
Rotalia maculata Stache	278	24	28	1	HT m.	1866 VIII 111
——— *naticoides* Stache	276	24	26	1	HT m.	1866 VIII 109
——— *paupercula* Stache	277	24	27	1	HT m.	1866 VIII 110
——— *soldanii* d'Orb.	273	24	23, 24	4	Abb. Orig.	1866 VIII 107
——— *sulcigera* Stache	275	24	19	1	HT m.	1866 VIII 108
Textilaria capitata Stache	270	24	25	1	HT m.	1866 VIII 104
——— *carinata* d'Orb. var. *robusta* Stache (= var. *inflata* Stache)	271	24	22	1	HT m.	1866 VIII 106
——— *carinata* d'Orb. var. *antipodum* Stache (= var. *maorica* Stache)	271	24	21	1	HT m.	1866 VIII 105
——— *subrhombica* Stache	271	24	20	1	HT m.	1866 VIII 118

Es fehlen die Belegstücke zu:

Bulimina arcuata Stache
——— *pupula* Stache
——— *textilariformis* Stache
Cristellaria gyroscalprum Stache
Dentalina rotundata Stache
——— *vagina* Stache
Globigerina angipora Stache (= *conferta* Stache)
Guttulina obliquata Stache
——— *pusilla* Stache
Haplophragmium maoricum Stache
Hemicristellaria corculum Stache
——— *verrucosa* Stache
Lagena anomala Stache
——— *tenuistriata* Stache
Nodosaria dubiosa Stache
——— *subsimilis* Stache
Quinqueloculina sp.
Rosalina latifrons Stache

Das abgebildete Original zu *Cristellaria haasti* Stache ist, wie aus einem Begleitzettel hervorgeht, bereits im Hofmineralienkabinett in Verlust geraten; vorhanden ist eine Gesteinsprobe mit Fossilabdrücken.

II. Karrer, F., 1864: Die Foraminiferen-Fauna des tertiären Grünsandsteines der Orakei-Bay bei Auckland. *Novara-Exped., Geol. Theil, 1 (2)* : 71-86, Pl. 16.

Fundpunkt: Umgebung der Orakei-Bay bei Auckland, Neuseeland.
Stratigraphie: Tertiär.

Name	Seite	pl.	fig.	Zahl der Exempl.	Typus	Aqu.-Nr.
Amphistegina aucklandica Karrer	85	16	19	70	ST	1865 XXXVII 179
———— *campbelli* Karrer	84	16	18	17	ST	1865 XXXVII 178
———— *ornatissima* Karrer	85	16	20	7	ST	1865 XXXVII 180
Clavulina elegans Karrer	80	16	11	3	ST	1865 XXXVII 179
Cristellaria mamilligera Karrer	76	16	5	9	ST	1865 XXXVII 160
Dentalina aequalis Karrer	74	16	1	3	ST	1865 XXXVII 156
Lingulina costata d'Orb.	75	16	3	1	Abb. Orig.	1865 XXXVII 158
Marginulina neglecta Karrer	75	16	4	1	HT. m	1865 XXXVII 159
Nodosaria spinicosta d'Orb.	73	—	—	1	Beschr. O	1865 XXXVII 154
Nonionina simplex Karrer	83	16	17	4	ST	1865 XXXVII 157
Orbitulites incertus Karrer	79	16	10	1	HT. m.	1865 XXXVII 169
Polystomella fichtelliana d'Orb.	83	16	15	1	Abb. Orig.	1865 XXXVII 175
———— *tenuissima* Karrer	83	16	17	1	HT. m.	1865 XXXVII 177
Robulina regina Karrer	76	16	4	1	HT. m.	1865 XXXVII 163
Rosalina mackayi Karrer	82	16	14	12	ST	1865 XXXVII 173
———— *perforata* Karrer	81	16	13	60	ST	1865 XXXVII 172
Textilaria hayi Karrer	78	16	7	1	HT. m.	1865 XXXVII 166
Vaginulina recta Karrer	74	16	2	6	ST	1865 XXXVII 157

Es fehlen die Belegstücke zu:

Orbitoides orakeiensis Karrer
Rotalia novo-zelandica Karrer
Textilaria convexa Karrer
———— *minima* Karrer

III. Zittel, K. A., 1864: Fossile Mollusken und Echinodermen aus Neuseeland. *Novara-Exped., Geol. Theil, 1 (2)* : 17-68, Pl. 6-15.

A. Trias

Lamellibranchiata:

Monotis salinaria var. *richmondiana* Zittel, p. 26, pl. 6, fig. 1a (Aqu-Nr. 1959/335/1; das ursprünglich grössere Belegstück mit zahlreichen Monotis-Resten ist zerbrochen!), fig. 1b (1959/335/2; Gesteinsstück mit 3 Schalen-Resten. Die Identifizierung mit der Abbildung ist nicht gesichert). —Umgebung von Richmond, unweit Nelson, Südinsel.

B. Jura und Kreide

Lamellibranchiata:

Aucella plicata Zittel, p. 32, pl. 8, fig. 4a-c (Aqu-Nr. 1959/335/3). 6 Exemplare, ST.—Waikato Southhead.

Inoceramus haasti Hochstetter, p. 33, pl. 8, fig. 5a (1959/335/4), 5b (1959/335/5), 5c (1959/335/6) + 2 nicht abgebildete Exemplare (1959/335/7-8). Abb. Orig.—Takatahi am Kawhia-Hafen an der Westküste der Nordinsel von Neuseeland.

Cephalopoda:

Belemnites aucklandicus Hauer, p. 29, pl. 8, fig. 2a-d (Aqu-Nr. 1959/335/53). 4 Exemplare und 1 Fragment, ST. Die Exemplare lassen sich mit den Abbildungen identifizieren. Waikato Southhead.

Belemnites aucklandicus var. *minor* Hauer, p. 29, pl. 8, fig. 3a-d (Aqu.-Nr. 1959/335/54). 5 Exemplare, ST. Ahuahu Point, Kawhia Hafen.

C. Tertiär

Brachiopoda:

Rhynchonella nigricans Sow., p. 60, pl. 14, fig. 5a-d (non fig. 4!) (1959/335/9). 7 Exemplare, Abb. Orig.—Kohuroa (Mahe Point), südlich Rodney Point.

Terebratella dorsata Gmel., p. 57, pl. 14, fig. 6 (non fig. 5!) (1959/335/10). 18 Exemplare. Abb. Orig.—Kohuroa (Mahe Point), südlich Rodney Point.

Terebratulina sp., p. 57, pl. 9, fig. 6a-c (1959/335/11). 6 Exemplare. Abb. Orig.—Waikato Southhead.

Waldheimia gravida Suess, p. 56, pl. 9, fig. 5 (1959/335/12). 2 Exemplare.Abb . Orig.—Papakura, Prov. Auckland.

Waldheimia lenticularis Desh., p. 56, pl. 10, fig. 3a und 4 (1959/335/13), fig. 3b (1959/335/14). Fig. 3a, 4—ein Exemplar, Westküste nordlich vom Whaingaroa-Hafen; fig. 3b—vier Exemplare, Murray-Cliff, Süd-Australien.

Gastropoda:

Buccinum robinsoni Zittel, p. 36, pl. 13, fig. 4 (1959/335/15). 1 Exemplar. HT m.—Cliffs in der Blind-Bay bei Nelson.

Crepidula incurva Zittel, p. 44, pl. 15, fig. 9 (1959/335/29). 7 Exemplare. ST.—Awatere-Tal.

Crepidula sp., p. 44, pl. 15, fig. 10 (1959/335/30). 2 Exemplare. —Awatere-Tal.

Natica solida Sow., p. 42, pl. 15, fig. 6a, b (1959/335/16). 1 Exemplar. Abb. Orig.—Awatere-Tal.

Purpura conoidea Zittel, p. 37, pl. 15, fig. 5 (1959/335/17). 1 Exemplar. HT m.—Awatere-Tal.

Purpura textiliosa Lam., p. 37, pl. 14, fig. 1 (1959/335/18). 1 Exemplar. Abb. Orig.—Rodney Point, Prov. Auckland.

Scalaria browni Zittel, p. 42, pl. 9, fig. 9 (1959/335/19). 1 Exemplar. HT. m.—Aotea-Hafen.

Scalaria lyrata Zittel, p. 41, pl. 9, fig. 8 (1959/335/20). 1 Exemplar. HT m.—Aotea-Hafen.

Struthiolaria canaliculata Zittel, p. 34, pl. 15, fig. 1 (1959/335/21-22). 2 Exemplare. ST.—Awatere-Tal.

Struthiolaria cingulata Zittel, p. 35, pl. 14, fig. 2 (1959/335/23). 3 Exemplare. ST.—Awatere-Tal.

Trochita dilatata Sow., p. 43, pl. 15, fig. 8 (1959/335/24). 2 Exemplare. Abb. Orig.—Awatere-Tal.

Trochus stoliczkai Zittel, p. 40, pl. 15, fig. 7 (1959/335/25). 10 Exemplare. ST.—Awatere-Tal.

Turbo superbus Zittel, p. 39, pl. 14, fig. 2 (1959/335/26). 1 Exemplar. HT m.—Rodney Point, nördlich Auckland.

Voluta gracilicostata Zittel, p. 38, pl. 13, fig. 6 (1959/335/27). 1 Exemplar. HT m.—Cliffs bei Nelson.

Voluta pacifica Sol., p. 38, pl. 15, fig. 4 (1959/335/28).—1 Exemplar. HT m.—Awatere-Tal.

Lamellibranchiata:

Dosinia greyi Zittel, p. 45, pl. 15, fig. 11 (1959/335/31). 5 Exemplare. ST.—Awatere-Tal.

Limopsis insolita Sow., p. 48, pl. 13, fig. 1 (1959/335/32). 1 Exemplar. Abb. Orig.—Cliffs in der Blind-Bay bei Nelson.

Ostrea ingens Zittel, p. 54, pl. 13, fig. 3 (1959/335/33). 1 Exemplar. HT m.—Wanganui River.

Ostrea nelsoniana Zittel, p. 55, pl. 11, fig. 7 (1959/335/34). 1 Exemplar. HT m.—Cap Farewell.

Ostrea wüllerstorfi Zittel, p. 54, pl. 11, fig. 6 (1959/335/35). 1 Exemplar. HT m.—Westküste der Provinz Auckland nördlich des Whaingaroa-Hafens.

Panopaea sp., pl. 9, fig. 7 (1959/335/36). 1 Exemplar.—Aotea-Hafen.

Pecten athleta Zittel, p. 49, pl. 10, fig. 1 (1959/335/37).—1 Exemplar. HT m.—Motupipi in der Massacre-Bay.

Pecten aucklandicus Zittel, p. 53, pl. 9, fig. 1a (1959/335/38). 1 Exemplar. HT m.—Orakei-Bay.

Pecten burnetti Zittel, p. 51, pl. 10, fig. 2a, b (1959/335/39). 3 Exemplare. ST.—Motupipi in der Massacre-Bay.

Pecten fischeri Zittel, p. 53, pl. 9, fig. 1c, 2 (1959/335/40). 2 Exemplare. ST.—Papakura, Prov. Auckland.

Pecten hochstetteri Zittel, p. 50, pl. 11, fig. 5a (1959/335/41). 1 Exemplar. HT m.—Westküste, nördliche vom Whaingaroa (nicht Farewell!).

Pecten polymorphoides Zittel, p. 51, pl. 11, fig. 3 (1959/335/42). 1 Exemplar. HT m.—Waikato Southhead.

Pecten triphooki Zittel, p. 52, pl. 11, fig. 4 (1959/335/43). 1 Exemplar. HTm.—Hawkes-Bay, Nordinsel.

Pecten williamsoni Zittel, p. 50, pl. 9, fig. 11 (1959/335/44). 4 Exemplare. ST.—Aotea-Hafen.

Pecten sp., p. 53, pl. 9, fig. 3 (1959/335/45). 1 Exemplar.—Papakura, Prov. Auckland.

Pectunculus laticostatus Quoy et Gaim., p. 48, pl. 15, fig. 13 1959/335/46). I Exemplar. Abb. Orig.—Awatere-Tal.

Teredo heaphyi Zittel, p. 45, pl. 14, fig. 4 (1959/335/47). 3 Exemplare. ST.—Rodney Point.

Crustacea:

Cirripedien-Schalen, pl. 9, fig. 12 (1959/335/48). 2 Exemplare. Abb. Orig.—Whaingaroa und Aotea.

Echinodermata:

Brissus eximius Zittel, p. 65, pl. 12, fig. 3 (1959/335/49). 1 Exemplar. HT m.—Motupipi, Prov. Nelson.

Hemipatagus formosus Zittel, p. 63, pl. 12, fig. 2 (1959/335/50). 2 Exemplare. ST.—Cap Farewell.

Hemipatagus tuberculatus Zittel, p. 63, pl. 12, fig. 1 (1959/335/51). 1 Exemplare. HT m.—Cap Farewell.

Schizaster rotundatus Zittel, p. 64, pl. 11, fig. 1 (1959/335/52). 1 Exemplar. HT m.—Waikato Southhead.

Es fehlen die Belegstücke zu:

Trias *Halobia lommeli* Wissm.
Mytilus problematicus Zittel
Spirigera wreyi Suess*

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*Das Material von *Spirigera wreyi* Suess konnte ich bisher noch nicht in unserer grossen Sammlung finden; es ist aber anzunehmen, dass auch dieses Material in Wien ist.

Jura *Ammonites novo-zelandicus* Hauer
Placunopsis striatula Zittel

Tertiär *Crassatella ampla* Zittel
Cucullaea singularis Zittel
Dentalium mantelli Zittel
Fasciculipora mammillata Zittel
Leda sp.
Neritopsis sp.
Nucleolites papillosus Zittel
Solenella australis (Quoy et Gaim.)
Struthiolaria sp.

IV Jaeger, G., 1864: Bericht über einen fast vollständigen Schädel von Palapteryx. *Novara-Exped., Geol. Theil, 1 (2)* : 307-18, Pl. 25-26.

Palapteryx ingens Owen.

V. Reuss, A. E., 1866: Über fossile Korallen von der Insel Java. *Navara-Exped., Geol. Theil, 2* : 165-85, 3 Pl.

Fundort: Gunung Sela im Tji-Lanangtal, Distrikt Rongga, Java.
Stratigraphie: Jung-Tertiär.

Alveopora brevispina Reuss, p. 178, pl. 3, fig. 7a-c (non fig. 6, wie im Text angegeben ist!). (1959/334/1). 1 Exemplar. HT m.

Alveopora hystrix Reuss, p. 179, pl. 3, fig. 8a-c (1959/334/2). 1 Exemplar. HT m.

Alveopora polycantha Reuss, p. 178, pl. 3, fig. 6a, b (non fig. 5!). (1959/334/3). 1 Exemplar. HT m.

Cycloseris nicaeensis Mich. ?, p. 169, pl. 1, fig. 5a, c (1959/334/4), fig. 5b (1959/334/5). 2 Exemplare. Abb. Orig.

Dictyaraea anomala Reuss, p. 177, pl. 3, fig. 3, 4 (1959/334/6). 1 Exemplar. HT m.

Dictyaraea micrantha Reuss, p. 176, pl. 2, fig. 6a-b, pl. 3, fig. 1, pl. 3, fig. 2 (1959/334/7-8). 2 Exemplare. ST.

Favoidea junghuhni Reuss, p. 168, pl. 1, fig. 4 (1959/334/9). 1 Exemplar. HT m.

Litharaea affinis Reuss, p. 175, pl. 2, fig. 5a-c (1959/334/10-11). 2 Exemplare. ST.

Madrepora duncani Reuss, p. 171, pl. 2, fig. 2a, b (1959/334/12), fig. 2c (1959/334/13). 2 Exemplare. ST.

Madrepora herklotsi Reuss, p. 170, pl. 2, fig. 1a, b (1959/334/14), fig. 1c (1959/334/15-16). 3 Exemplare. ST.

Pocillipora jenkinsi Reuss, p. 181, pl. 3, fig. 10 (non fig. 9!). 1 Exemplar. HT m. (1959/334/17).

Porites incrassata Reuss, p. 174, pl. 2, fig. 4a, b (1959/334/18). 1 Exemplar. HT m.

?*Prionastraea dubia* Reuss, p. 167, pl. 1, fig. 3 (1959/334/19). 1 Exemplar. HT m.

Stylocoenia depauperata Reuss, p. 166, pl. 1, fig. 1a, b(1959/334/20). 1 Exemplar. HT m.

Es fehlen die Belegstücke zu:

Anisocoenia crassiseptata Reuss
Beaumontia inopinata Reuss
Dendracis haidingeri Reuss
Polysolenia hochstetteri Reuss

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STOLICZKA, F., 1864: Fossile Bryozoen aus dem tertiären Grünsandsteine der Orakei-Bay bei Auckland mit Betrachtungen über neue oder weniger bekannte Bryozoen-Sippen und deren Classification *Novara-Exped., Geol. Theil, 1 (2)* : 89-158, Pl. 17-20.

UNGER, FR., 1864: Fossile Pflanzenreste aus Neuseeland. *Novara-Exped., Geol. Theil, 1 (2)* : 3-13, Pl. 1-5.

ZITTEL, K. A. v., 1864: Fossile Mollusken und Echinodermen aus Neuseeland. *Novara-Exped., Geol. Theil, 1 (2)* : 17-68, Pl. 6-15.

APPENDIX

NOTES ON THE LOCALITIES OF NEW ZEALAND FOSSILS COLLECTED BY THE NOVARA EXPEDITION

By C. A. FLEMING and N. DE B. HORNIBROOK

The following notes on the localities, stratigraphy, and age of fossils collected by Hochstetter have been drawn up at the suggestion of Dr E. Flügel to supplement his list of types and figured specimens preserved in the Vienna Natural History Museum. Where possible, localities are stated in terms of the sheets of the New Zealand Mapping Service Series I maps, and by 6-figure grid references to their current editions. Details of the stratigraphic units cited (formations and stages) may be obtained from the *Lexique Stratigraphique International* (Fleming, 1959).

The fossil localities are arranged in order of age—Triassic, Jurassic, Tertiary, and Holocene, and Tertiary localities are listed in geographic order from north to south. Except where otherwise noted, the fossils were described by Zittel (1864).

TRIASSIC

RICHMOND, NEAR NELSON: Hochstetter's specimens of *Monotis salinaria* var. *richmondiana* Zittel were from blocks on the surface on the slopes east of Richmond (S20, grid ref. approx. 542192). The fossil is the key species of the Warepan Stage, Balfour Series, Hokonui System, correlated with the Norian (Marwick, 1953, p. 17).

Hochstetter collected the internal moulds that constitute the syntypes of *Spirigera wreyi* Suess on the slopes of Aniseed Valley and at Spring Grove, Wairoa Valley, with *Mytilus problematicus* Zittel (Otamitan Stage, Carnian). The New Zealand Geological Survey received casts from some of this material from Vienna in 1952, but Dr Flügel was unable to locate the originals in 1959 (see footnote, p. 838).

JURASSIC

WAIKATO SOUTH HEAD: The locality (N51, grid ref. 233940) has been described by Purser (in press), and is now attributed to the Plicata Zone of the Puaroan Stage, Oteke Series, Hokonui System, correlated with the lower Tithonian (Fleming and Kear, in press).

TAKATAHI, KAWHIA HARBOUR: The locality, described in more detail by Hochstetter (1864, p. 32), is near Kowhai Point, west of Takatahi

N73, grid ref. 333061) in the Kowhai Point Siltstone, type section of the Ohauan Stage, Kawhia Series, Hokonui System (Marwick, 1953), correlated with the Middle Kimeridgian (Fleming and Kear, in press). *Inoceramus haasti* Hochstetter is the key species to the Ohauan.

AHUAHU, KAWHIA: The section at Ahuahu (Te Waitere, Lemon Point) is described by Fleming and Kear (in press). The source of the belemnites collected by Hochstetter is a silstone formation containing ammonites (*Kossmatia, Paraboliceras*, etc.) classed as Middle Kimeridgian by the late Dr W. J. Arkell.

TERTIARY

North Island

CAPE RODNEY: The fossils were collected for Hochstetter by Charles Heaphy from the place specified as Kohuroa (Mahe Point), south of Rodney Point, in the caption to Zittel's Plate 14. This locality, on the coast south of Kohuroa Stream (N34, grid ref. 308269) is in angular breccia at the base of the Waitemata Sandstone, unconformably overlying Permian-Jurassic greywacke. The base of the Waitemata Sandstone is now classed in the Otaian Stage, Pareora Series, correlated with the Upper Oligocene.

ORAKEI BAY: The Orakei Bay Greensand, from which Hochstetter collected the Foraminifera and Mollusca described by Karrer (1864) and Zittel (1864) cropped out near the NE end of the Hobson Bay sewer (N42; grid ref. approx. 327598) but its exposure has been largely covered by debris from road construction. It ranks as a member of the Waitemata Sandstone. Until recently the Orakei Greensand was considered to be of Altonian age (Lower Miocene) but is now correlated with the Otaian (Upper Oligocene) by Foraminifera (Hornibrook, 1959, p. 293).

PAPAKURA: Hochstetter (1864, p. 42) obtained his collection from "Cooper's and Smith's limestone quarries" on the north-west slope of Hunua Range, five to six miles from Papakura (N46), but the exact localities have not been found. The Papakura Limestone, from microfaunal samples collected in other parts of its outcrop, is classed in the Otaian (Upper Oligocene) and is thus approximately coeval with the Orakei Bay Greensand, as Hochstetter believed (1864, p. 43).

WAIKATO SOUTH HEAD: The faulted outcrop from which Hochstetter collected (1864, p. 28) has been re-described by Gilbert (1921, p. 102) and by Purser (in press). It lies in N51, grid ref. 235942. The fossiliferous calcareous sandstone is now classed in the Whaingaroan Stage, Landon Series, correlated with the Lower Oligocene.

WEST COAST NORTH OF WHAINGAROA HARBOUR: Hochstetter (1864, p. 44) described a rich fossil locality several miles along the coast north of the north head of Whaingaroa Harbour (now known as Raglan Harbour, N64) from which Zittel described *Ostrea wullerstorfi*

Zittel, *Pecten hochstetteri* Zittel, and figured a specimen as *Waldheimia lenticularis* (Deshayes). The exact locality has not been re-described. The beds are probably Duntroonian or Waitakian (Lower or Middle Oligocene).

WHAINGAROA (RAGLAN) HARBOUR: The locality from which Haast and Hochstetter collected the rich fauna of Foraminifera described by Stache is stated by Hochstetter (1864, p. 44) to be "the shore of Waitetuna Creek, near Captain Johnston's house". The beds are "light grey, somewhat sandy clay marls", now called Whaingaroa Mudstone. The locality has not been confidently identified, but lies in N64 (approximate, grid ref. 487465). The Whaingaroa Mudstone is the type formation of the Whaingaroan Stage, Landon Series (Lower Oligocene).

Whaingaroan microfaunas lack such characteristic Eocene elements as Discocyclinidae, *Hantkenina*, "*Globigerinella*" *iota*, (aff. *mica*), and *Globigerapsis index*, all of which occur in the underlying Runangan Stage. The Runangan is correlated with Upper Eocene and the Whaingaroan with Lower Oligocene (Hornibrook, 1958).

In the text of Stache's report (p. 229) *Hemirobulina compressa* Stache is described as compressed, with dimensions 1·25 × 0·56 × 0·30 mm, and with a reference to pl. 23, fig. 8, where a specimen with almost identical measurements is figured at a magnification of 20/1; *H. galeola* (p. 228) is described as 0·73 × 0·43 × 0·42 mm with a reference to pl. 23, fig. 7, showing a specimen (20/1) with approximately the latter dimensions. In the plate caption and index (p. 302) the names for these two species are transposed. Apparently the labels now associated with the type specimens agree with the caption and not with the text (see table, section I). However, in view of Stache's clear intention, in the text, to name the larger form *compressa* and the smaller *galeola*, and of the possibility that labels have been subsequently transposed to agree with the captions, the nomenclature of the two species figured cannot be considered settled.

AOTEA HARBOUR: Hochstetter (1864, p. 45) obtained the collections from Aotea Harbour from fossiliferous calcareous sandstone (now known as Aotea Sandstone, overlying the Whaingaroa Mudstone) at Puketoa Cliff (N64, grid ref. 379209). The Aotea Sandstone is Whaingaroan (Lower Oligocene).

HAWKES BAY: *Pecten triphooki* Zittel was described from a specimen sent to Hochstetter by the surveyor T. D. Triphook, collected from "Tertiary Limestone, at Petane and on Scinde Island". The latter locality at Milton Rd, Napier (N134, grid ref. 323000), is the restricted type locality of *P. triphooki*, a common Pliocene to Lower Pleistocene fossil in New Zealand. The Scinde Island Limestone with *P. triphooki* is now classed in the Hautawan Substage of the Nukumaruan Stage, Wanganui Series, correlated with the Lower Pleistocene.

WANGANUI RIVER: Hochstetter (1864, p. xi) did not state the source of the specimen described as the type specimen of *Ostrea ingens* Zittel, but may have obtained it from Mantell, whom he quotes at the reference cited. The most likely locality in the lower Wanganui Valley is where the Wilkies Shellbed (Waitotaran Stage, Pliocene) crosses the Wanganui—Pipiriki Road (N138, grid ref. 674067); the shellbed is largely composed of complete shells of this giant oyster.

South Island

CAPE FAREWELL: Hochstetter's fossils were collected from calcareous sandstone containing abundant echinoderms at a promontory near the west end of Farewell Spit (S1, grid ref. 233141), still called the Fossil Point on current maps. The fauna is now classed in the Otaian Stage, Pareora Series (Upper Oligocene).

MOTUPIPI, MASSACRE (GOLDEN) BAY: The fossils were collected "opposite the public house at Motupipi, at the so-called Fossil Point" (Hochstetter, 1864, p. 239) from the Takaka Limestone, and are classed in the Waitakian Stage, Landon Series (Middle Oligocene). *Athlopecten athleta* (Zittel) is, indeed, a reliable index fossil for the Waitakian. The locality is in S8, approximate grid ref. 232841.

THE CLIFFS, BLIND BAY, NELSON: This locality had already been collected by the famous nineteenth-century collector Hugh Cuming, and the fossils described by Forbes (1850), before it was visited by Hochstetter. In S20, at grid ref. 607293, poorly preserved abundant fossils occur on the shore below the water-front road from Nelson to Tahunanui in graded bedded siltstones and poorly sorted glauconitic breccies. These sediments are part of the Jenkins Hill Beds of Mackay (1878), and the fossils are now believed to be Whaingaroan or Duntroonian (Lower Oligocene).

AWATERE VALLEY: The locality described by Hochstetter (1864, p. 215) refers to the Upton Group (Kapitean and Opoitian stages, Upper Miocene—Lower Pliocene) near Black Birch and Blairich streams, joining the Awatere River, 5 to 6 miles SW of Taylors Pass, but the fossils include species probably from the overlying Starborough Group (Waitotaran Stage, Upper Pliocene) which are best exposed in Starborough Creek, near Seddon. The collections were "obtained from friends in Nelson" so are probably from several localities.

HOLOCENE

The skull described as *Palapteryx ingens* by Jaeger was found by Haast in what he termed "Hochstetter's Cave" in the wooded knoll of Oligocene limestone above Washbourne's Flat in the Aorere Valley (Hochstetter, 1864, p. 244). Archey (1941, p. 70) considered it to be probably *Dinornis torosus* Hutton, though possibly *D. robustus* Owen,

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DRURY COALFIELD, AUCKLAND

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(Received for publication, 31 August 1959)

Summary

Dr F. von Hochstetter's first New Zealand geological publication described the Drury Coalfield. Coal measures, at the base of the Te Kuiti Group, contain dirty thin coal seams, and only about 8,000 tons of sub-bituminous coal have been mined in 100 years. The measures are overlain conformably by Whaingaroan Mangakotuku Siltstone in the south, and unconformably by Otaian Waitemata Group (including Papakura Limestone) in the north. Following block faulting, basalt was extruded up fault planes.

No worth-while reserves of coal are present in the coalfield; road metal and clay are more important economic deposits than coal.

INTRODUCTION

The first geological account of the Drury Coalfield was that of Dr F. von Hochstetter (1859a), published in the *New Zealand Gazette* of 13 January 1859. In 1858, coal had been found by the Rev. A. G. Purchas (Hochstetter, 1867, p. 78), and in the following year (Hochstetter, 1864a, p. 52) was mined and sold in Auckland at 30s. to 32s. per ton. Hochstetter (1859a) visited four outcrops at Drury and Opaheke, and inferred the presence of a single 6 ft seam which consisted of beds of coal, up to 2 ft 6 in. thick, separated by bands of shale. As the coalfield is only 20 to 30 miles south-east of Auckland (Fig. 1a), it is therefore unfortunate that the 11 mines that have operated there in four distinct mining sections (Drury, Bombay, Hunua, and Opaheke, Fig. 1b) have all found similarly thin and dirty coal. Their total production had amounted to only about 8,000 tons.

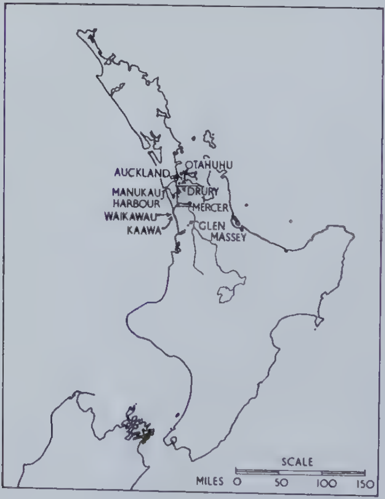


FIG. 1a.—Locality map.

The coalfield is bounded (Figs 1b, 2) to the east by the Wairoa Fault (Wairoa River Fault of Mead, 1930b), which throws up the high greywacke range of the Hunua uplands; to the north by the lowlands of the Papakura Valley depression; to the west by the Drury Fault (the Papakura-Drury Fault of Laws, 1931, p. 59; see Schofield, 1958b,

N.Z. J. Geol. Geophys. 2 ; 846-69.

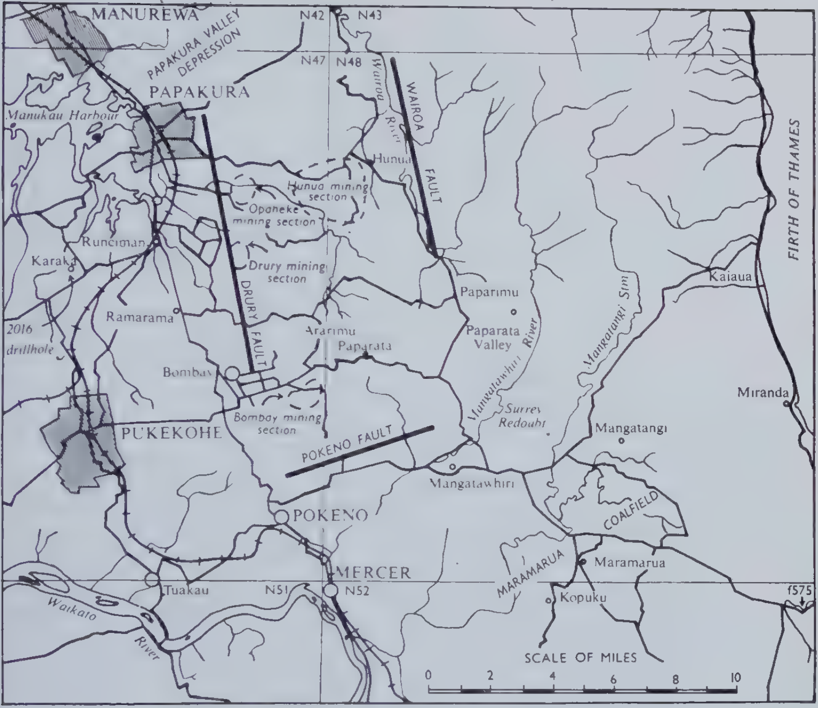
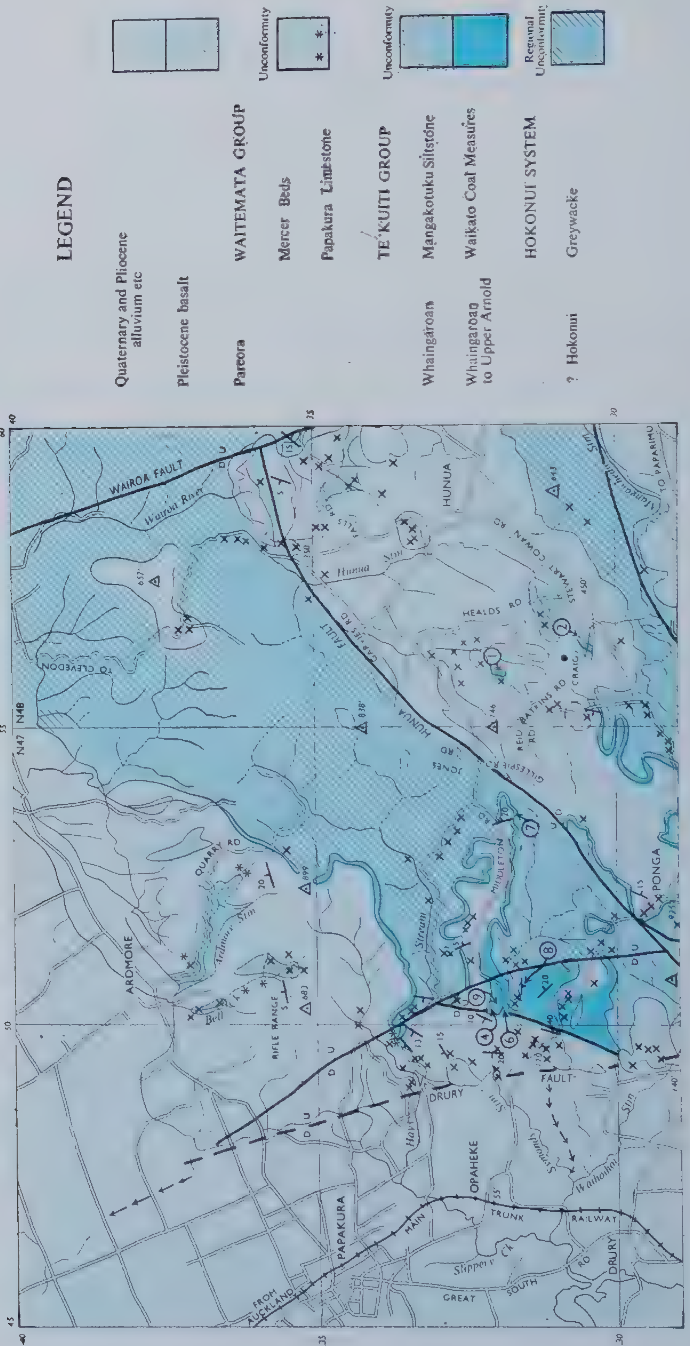


FIG. 1b.—Detail map of area outlined in Fig. 1a.

p. 541), which downthrows the Tertiary beds deeply below the Quaternary deposits of the Manukau lowlands; and to the south by the summit line of the "Bombay Hills" and their eastward extension on the northern side of the Pokeno Fault (Bartrum and Branch, 1936, p. 387). Within this block, the landscape is formed predominantly of rugged "greywacke" hills which locally rise to more than 1,000 ft above sea-level and are capped along some ridges, especially in the west, by rolling land underlain by Tertiary beds. Much land is scrub-covered, with notable exceptions in those areas that are underlain by Quaternary sediments.

The southern boundary is arbitrary, and separates the Drury Coalfield from the northernmost part of the Maramarua Coalfield at Surrey Redoubt (Lyons, 1932, p. 270). Denniston (1877, pp. 119–20) recorded 9 ft of coal in a drillhole at Surrey redoubt, and Mr H. E. Fyfe (pers. comm.) considers that the reported thickness of 12 ft of coal at Mangatangi Mine was consistent with what could be seen in 1945. Such thicknesses ally the coal with the thick seams of Maramarua rather than with the thin seams of Drury.

Early descriptions of the geology and mining of the coalfield by Hochstetter (1859a, 1859b, 1864a, 1864b, 1867), Weekes (1860), and Hector (1870), were followed by a number of papers (Hutton, 1867,


LEGEND
Quaternary and Pliocene alluvium etc
Pleistocene basalt
Pareora
WAITEMATA GROUP
Mercer Beds
Papakura Limestone
Unconformity
TE KUITI GROUP
Whaingaroan
Mangakotuku Siltstone
Whaingaroan to Upper Arnold
Waikato Coal Measures
Unconformity
HOKONUI SYSTEM
? Hokonui
Greywacke
Regional Unconformity
WAIROA FAULT
Wairoa River
TO CLEVEDON
HUNUA FAULT
HUNUA
Hunua Stm
FALLS RD
GARVIES RD
HEALDS RD
STEWART COWAN RD
JONES RD
GILLESPIE RD
REID RD
RAWLINS RD
CRAIG RD
MIDDLETON RD
TO PAPARIMU
PONGA
ARDMORE
QUARRY RD
Ardmore Stm
Bell
RIFLE RANGE
DRURY
FAULT
Hays Stm
Symonds Stm
Waihoihoi Stm
OPAHEKE
PAPAKURA
FROM AUCKLAND
MAIN TRUNK RAILWAY
Slippery Ck
GREAT SOUTH RD
DRURY
N47
N48

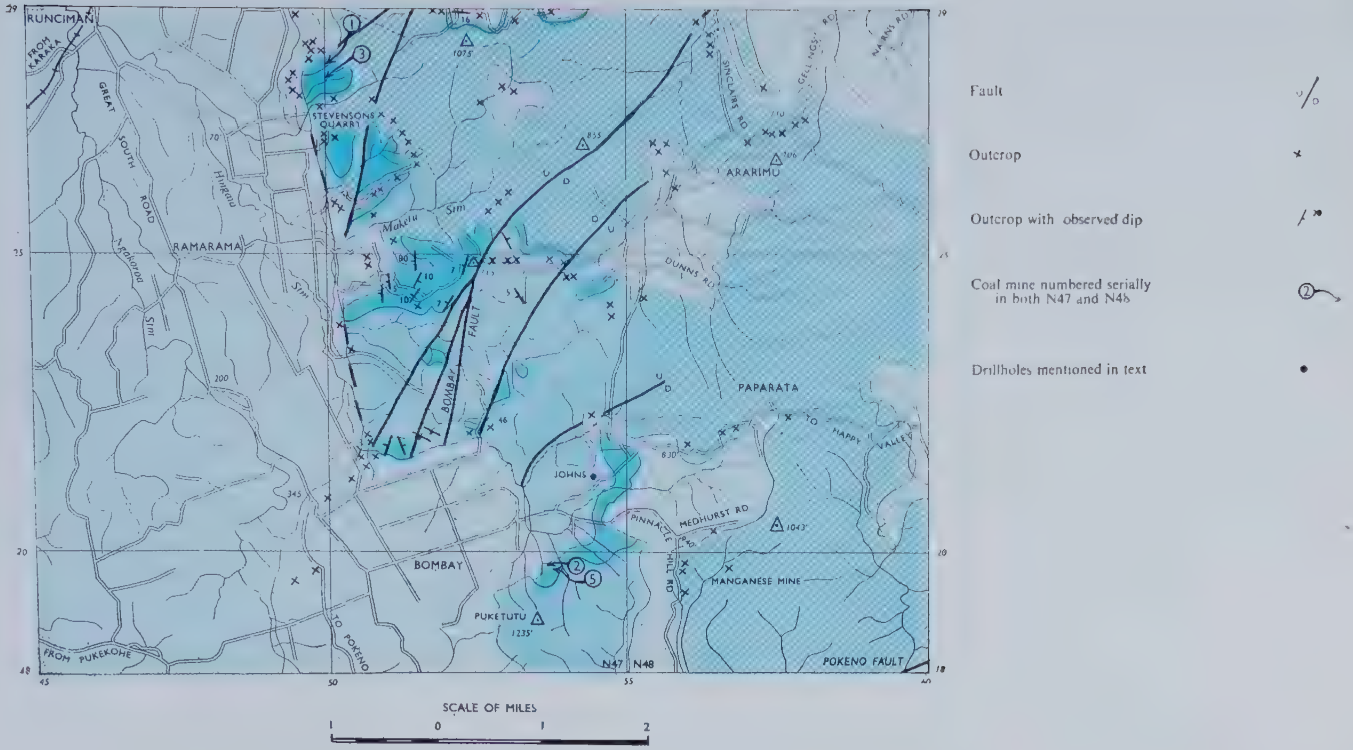


FIG. 2.—Geology of Drury Coalfield.

1871, 1872, 1890; Cox, 1882; Park, 1886, 1890; McKay, 1888a, 1888b; and Clarke, 1905, 1910), in which the problems of the stratigraphic relationships of the coal measures, and the overlying Papakura and Waitemata Series were constantly discussed. Nevertheless, many years elapsed before publication of the results of geological mapping of a sufficiently high standard to answer these problems. Papers by Mead (1930a, 1930b), Laws (1931), Healy (1935), and Bartrum and Branch (1936) included parts of the Drury Coalfield, whilst Firth (1930), Brown (1942), and Battey (1949) mapped areas to the north, east, and south respectively. These authors' papers should be consulted for information on the detailed physiography.

The present paper is based upon the results of several short economic surveys of parts of the coalfield by the writer, often with Mr J. C. Schofield, during 1950–9. The accompanying geologic map (Fig. 2) is compiled from new surveys, from air photographs, and from the maps of Mead (1930b), Laws (1931), Bartrum and Branch (1936), and Schofield (1958b). Figure 3 presents two diagrammatic sections.

The microfaunal age determinations quoted are the work of Mr N. de B. Hornibrook, and microfloral age determinations of Dr R. A. Couper and Mr D. McIntyre.

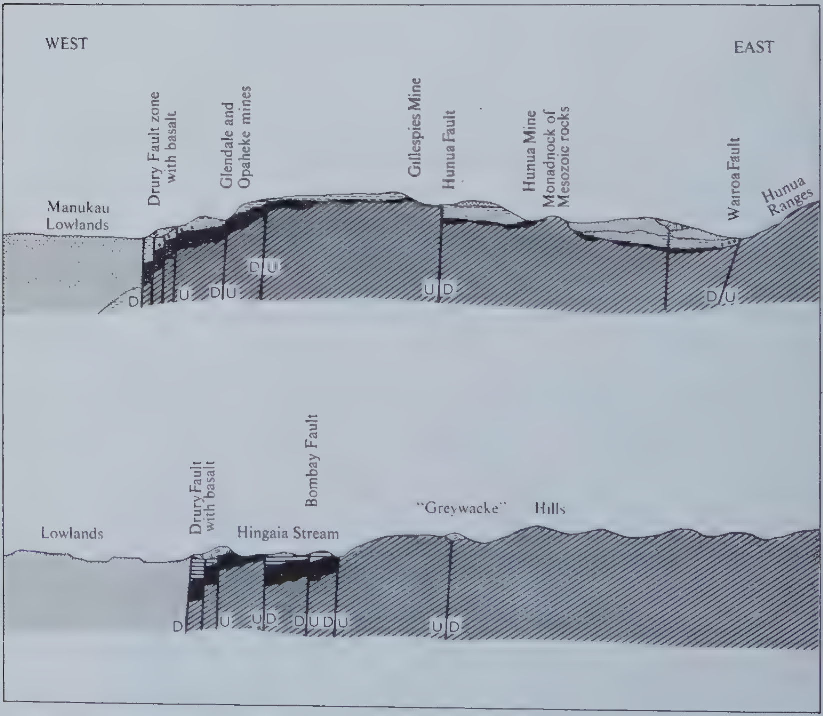


FIG. 3.—Diagrammatic east-west sections across the northern (above) and southern (below) parts of the Drury Coalfield. The plane of only the Wairoa Fault has been observed, and the other faults are shown arbitrarily as being vertical.

STRATIGRAPHY

General

In the southern part of the coalfield, Whaingaroan marine beds and overlying coal measures (both of the Te Kuiti Group) rest unconformably upon Hokonui greywackes. In the north, the Waitemata beds overstep across an eroded surface of coal measures on the greywacke basement rocks. Locally, these Waitemata beds rest directly upon greywacke.

Following late Tertiary block-faulting, the lower-lying areas were filled with alluvial (and less commonly marine) pumiceous sediments, and basaltic volcanics were erupted at points along the fault planes.

Table 1 illustrates the succession:

Table 1.

		Ft
Quaternary to Pliocene	Clays, pumiceous alluvium	0–200
	Basaltic volcanics	
	Pumiceous alluvial and marine sands	
	Unconformity	
Pareora Series	Waitemata Group	
	Mercer Beds	
	Calcareous sandstones, siltstones, and conglomerates, with some carbonaceous beds, locally tuffaceous; some intraformational unconformities	200+
	Papakura Limestone	
	Limestone with sandstone beds	0–40
	Basal sandstone and conglomerate	0–20
	Unconformity	
	Te Kuiti Group	
Landon Series (Whaingaroan Stage)	Mangakotuku Siltstone	
	Glauconitic sandstone	50+
	Massive siltstone with common Foraminifera	100
	Glauconitic sandstone	0–150
Upper Arnold Series (locally lower Landon Series)	Waikato Coal Measures	
	Carbonaceous mudstone	100
	Coal	0–6
	Carbonaceous mudstone and sandy fireclay	25
	Regional Unconformity	
Hokonui System	Greywacke, mainly medium-coarse massive sandstone	

Hokonui System

Hokonui rocks form the high ranges east of Hunua, and are the commonest surface rocks in the coalfield itself. They contain "a moderate quantity of feldspar (dominantly various plagioclases), a variable amount of quartz in angular grains, tiny pellets of fine-grained acidic lavas, and fragments of pyroxenes and of hornblende showing definite degrees of chloritization" (Bartrum and Branch, 1936, p. 398). They are of very even, medium-coarse sandstone grade. Bedding, which is most obscure, even in fresh exposures, is quite indeterminate under the normal extremely weathered conditions. Joints are common and prominent, and their planes are often coated with a zeolite film. Argillites are present (e.g., at Stevenson's Quarry, south-east of Drury), but are not common.

No internal evidence of age has been found, although Jurassic (?Heterian Stage) fossils are known a short distance to the east across Wairoa Fault (Milligan, 1959).

TE KUITI GROUP

(Kear and Schofield, 1959, after Henderson and Ongley, 1923)

Pre-Coal Measures Surface

Laws (1931, pp. 56–7) thought that the surface on which the Tertiary sediments were laid down was of "very slight relief"; but he also inferred the presence of one monadnock and of cliffs of "no mean height". Bartrum and Branch's (1936, p. 388) view of a "moderate if not strong" relief fits better the observed facts of local basal conglomerates, often in marked depressions (e.g., above Stevenson's quarry), of probable monadnocks (e.g., 1½ miles north-north-east of Puketutu Trig. and east of Hunua Mine), and of thin dirty coal seams. The exposures near Waihoihoi Mine clearly show that the greywacke surface beneath the coal measures was considerably leached, probably during coal measure times. (Waihoihoi Mine is located in the hills east of Drury. As with all other mines, its grid reference, N47/501282, is given in Table 2, together with its mine number, N47 m1, by which it is identified in Fig. 2.)

WAIKATO COAL MEASURES

(Kear and Schofield, 1959: after Hutton, 1871)

Content and Distribution

The Waikato Coal Measures contain a single thin and dirty coal seam, which is interbedded with some 10 to 20 ft of light and dark carbonaceous mudstones containing good leaf impressions. The underlying beds are rarely exposed, but at Waihoihoi Mine comprise 25 ft of light-coloured carbonaceous mudstone and fireclays. Elsewhere, these basal beds may be represented by conglomerates (with greywacke pebbles to 6 in.) or quartz sandstones.

Above the seam, medium to dark grey carbonaceous mudstone is 100 to 150 ft thick in the western part of the coalfield from Bombay to Opaheke. The coal measures appear to thin eastwards towards Hunua,

TABLE 2.—Summary of Data, Obtained Largely from New Zealand "Mines Statements" Concerning the Coal Mines of the Drury Coalfield.

Mine number	Name	Alternative names	Area	Grid reference	Seam thickness Total (ft)	Seam thickness Wrkd. (ft)	Years worked	Output (tons)	Remarks
N47/m1	Waihoihoi	Chamberlain	Drury	N47/501282	6	4½	1859–65	Unknown	Possible output 500 to 2,500 tons. Abandoned due to uneven floor and high freight costs. Poor roof.
N47/m2	Bombay No. 1	Long	Bombay	N47/537197 (approx.)	2–5½	2–3	1894–8	81½	Mine wrongly placed in Mokau Coalfield by Henderson and Ongley (1923, p. 4).
N47/m3	Drury	Holden McEwen	Drury	N47/500279 (approx.)	6	6	1905–10	2689	"Drilled 15 ft seam" proved 6 ft, including stone on mining. Abandoned due to cost.
N47/m4	Opaheke	Brown Fraider	Opaheke	N47/502320	3–4	3–4	1923	49	Drive probably towards 335°. Abandoned as unprofitable.
N47/m5	Bombay No. 2	Brown	Bombay	N47/537197 (approx.)	3–4½	3–4	1923–4	313	Abandoned because too "faulty and stony". Dip SSW 7° (Bartrum and Branch, 1936, p. 400).
N47/m6	Glendale No. 1	Dunn Fraider Greenhorn Logan	Opaheke	N47/502319	5	3	1932–4	1299	Drive probably towards 055°. Closed in favour of No. 2 (m9) due to water.
N47/m7	Gillespies	Christopher	Hunua	N47/536317	3	3	1932	21	
N47/m8	Black Diamond	Gougher and Crump	Opaheke	N47/507316 (approx.)	2½	2½	1933	24	
N47/m9	Glendale No. 2	Fraider	Opaheke	N47/503320	4	4	1935	124	Drive probably towards 240°. Abandoned after hitting fault, 3 chains in.
N48/m1	Hunua	Davies Ellen Lewis Wallace Westhead	Hunua	N48/560320	4–6	3–5½	1919–21 1923–4	1983	Drive probably towards 185°. Abandoned due to difficulty of selling coal containing shale band.
N48/m2	Cowans	Greenhorn Hunua Marsh Stirling	Hunua	N48/565307	3–4	3–4	1932–4	350	Drive probably towards 010°.

however, where little or none is present above the coal. Bartrum (1922) described clay-coated greensand nodules on the outside surfaces of siderite concretions in the thin overlying coal measures at Hunua Mine (N48/m1).

The following drill-logs (Mr G. E. Nairn, driller, Ramarama, pers. comm.) refer to holes that penetrated coal measures.

Drillhole on R. John's Property.
(Grid Reference N47/544213—see Fig. 2)

	Ft to base of bed
Soil, etc.	8
Sand	11
Pipeclay (white plastic mud)	19
Fireclay	24
Blue sedimentary, puggy firm (carbonaceous mudstone)	42
Hard ditto	43
Blue sedimentary fireclay (cf. Kopuku)	122
Coal good hard bright	126
Variable sandstone layers very firm	188
Greywacke, broken at top	234

Drillhole on Craig's Property.
(Grid Reference N48/561309—see Fig. 2)

	Ft to base of bed
Loam, yellow clay	6
Hematitic mud	10
Fireclay white	34
Rotten timber (peat)	35
Brown sandstone (very soft)	55
Dark pug, carbonaceous mudstone, very sticky, firm	87
Coal, dirty	90
Light brown pug, very firm	119
Blue sandy papa (very hard) (cemented sandstone) [common drillers' description for coarse greywacke]	146

Age and Correlation

Laws's contention (1931, pp. 43, 45) that the coal overlies marine sandstone was not verified by his described sections, nor has it been by recent fieldwork. It is therefore assumed that, as the above drill-logs indicate, no Tertiary marine beds exist below the coal.

The oldest marine beds above the coal are Whaingaroan (Mangakotuku Siltstone) in the south, but are Otaian (Waitemata sandstone, conglomerate, and limestone) in the north-east. In the south (Bombay and Drury sections), Mangakotuku Siltstone overlies coal measures conformably, and in the north-west (Opaheke Section), pebbles of both Mangakotuku Siltstone and of coal measure are included in an Otaian conglomerate. Hence, the coal is considered to be basal Te Kuiti Group in both these areas. A similar age is also assumed for coal in the Hunua Section, implying an unconformity below the Otaian beds, which is consistent with the undoubted thinning of the Te Kuiti Group in a northerly and easterly direction as a result of pre-Waitemata erosion. In both Bombay and Hunua areas, the coal seams are invariably thin, dirty, and no higher in sulphur content beneath the marine Pareora sandstones at Hunua than they are below the coal measures elsewhere (see section on Quality of Coal, below).

Dicotyledonous leaf impressions and the fresh-water mollusc *Anodonta* have both been reported (Hochstetter, 1864a, p. 52; Penseler, 1930; Bartrum and Branch, 1936, p. 402), but have not given a precise age to the formation. Hochstetter (1859a) collected and described in some detail leaves from two of a number of localities of mining interest. With subsequent changes of land ownership, their precise locations are now uncertain, but it appears likely that: Mr Farmer's was the area around Waihoihoi and Drury mines (N47/m1, 3); Mr Hall's was in the basaltic area a mile to the north; Mr Pollock's shaft (one leaf collection locality, say, N 47/500310) was near the western extremity of coal measure outcrop on the Opaheke-Ponga Road, or within ½ mile to the south; Mr Pollock's tunnel was in the valley immediately to the north of this; Mr Symond's was in Symonds Stream about ½ mile below Opaheke Mine (N 74/m4); Mr Campbell's was at the sites of Opaheke and Glendale No. 1 mines (N 47/m4, 6); Mr Campbell's, towards Mr Clare's, was along the Hunua track from the above, possibly near Glendale No. 2 Mine (N 47/m9); Mr Fallwell's south shaft was near the Opaheke-Ponga road, nearly due south of Black Diamond Mine (N 47/m8); Mr Fallwell's north shaft was close to Black Diamond Mine; Mr Fallwell's cut (the second leaf collection locality, say, N47/507315) was between these two shafts; and Mr Falwell's, near Mr Clare's, was in Hokonui basement rocks in Symonds Stream upstream of Glendale No. 1 Mine.

Dr R. A. Couper (pers. comm.) has examined the spores and pollen grains from three coal samples. He reports that "among the species identified from N 47/512 (L 546), from near the mouth of Waihoihoi Mine, *Proteacidites* cf. *crassus* Cooks. and *Podocarpidites* cf. *ellipticus* Cooks. (last appearance under Arnold), together with *Nothofagus matauraensis* Coup. and *Tricolpites matauraensis* Coup. (Arnold to Landon) indicate an Arnold age. The absence of a number of species characteristic of lower Arnold (Bortonian, Kaiatan) floras in the South Island suggests this sample is probably upper Arnold (Runangan) in age" (as is a sample from Hays Stream, N 47/f567), beneath the Papakura Limestone, Mr D. McIntyre, pers. comm.). Samples from Gillespies (N 47/f520, L 547) and Hunua (N 48/f525, L 760) mines yielded only poor floras. They could be Arnold, but are more probably Landon (Dr R. A. Couper, pers. comm.). Slight age differences in different parts of the coalfield are to be expected, from the irregular pre-coal-measure topography. These ages are, however, taken to imply that the coals are all basal Te Kuiti Group.

MANGAKOTUKU SILTSTONE

(Kear and Schofield, 1959)

Distribution and Content

Exposures of the Mangakotuku Siltstone are restricted to the south-western part of the coalfield, between Bombay in the south and the Ramarama-Paparimu road in the north, 3 miles east of Ramarama.

Bartrum and Branch (1936, pp. 388–9) gave the following upwards sequence above the coal measures: green sandstone with some fossils, up to 150 ft thick but thinning out to little or nothing laterally; greyish or puce-coloured foraminiferal shales, 100 ft thick; thick dark greenish sandstones with some fossils. No good continuous sections were found in the recent fieldwork, and, indeed, none may exist. The best section is apparently in Hingaia Stream, a mile north of Bombay (see Schofield, 1958b, Fig. 5), but, although exposures are good, they are almost certainly faulted. Glauconitic sandstone with mollusc casts undoubtedly underlie grey or purplish-grey, non-calcareous mudstones that are fissile in part and usually contain prominent Foraminifera (*Arenodosaria antipoda*). Although the field evidence is inconclusive, further glauconitic sandstones with mollusc casts probably overlie the mudstone. Hence, Bartrum and Branch's sequence, though not actually confirmed, may well be correct.

Age and Correlation

Parr (1937) described Foraminifera from shales near Bombay, but came to no definite conclusions regarding their age.

A sequence of 25 ft of more or less glauconitic, calcareous sandstones and silty sandstones with fossil casts and fragile shells are well exposed in Hingaia Stream, ½ mile east of Drury Fault. Microfossil samples (N 47/f505–6, f529), collected from these beds, have been assigned a basal Whaingaroan age by Mr N. de B. Hornibrook (pers. comm.).

Beds that are similar to the "foraminiferal shales" of the Drury Coalfield are exposed in the Maramarua area, 10 miles south-east; and beds that are very similar in both stratigraphic position and lithology have been termed the Mangakotuku Siltstone (Kear and Schofield, 1959) in the Glen Massey Coalfield. These correlatives have also been assigned a basal Whaingaroan age on microfaunal evidence.

WAITEMATA GROUP

(Hochstetter, 1864b: XXXVIII, 39)

Terminology

The stratigraphic name "Papakura" has been used consistently since Hochstetter (1864b, pp. XXXVIII, 42–3) to designate a limestone formation. Clarke (1905) suggested that the type locality should be "Cooper and Smith's limestone quarries on the Hunua Mountains" (Zittel, 1864, p. 42).

Hutton (1871, p. 246) extended "Papakurá" to group status (as Papakura Series) to include all strata unconformably above the coal measures and reputedly unconformably below the Waitemata Series. Many subsequent writers (e.g., McKay, 1888a; Clarke, 1910, pp. 498–9) doubted the existence of the younger unconformity, and Park considered the Papakura Limestone to be at the base of the Waitemata Series (1890, pp. 394–5). These views no doubt influenced Firth (1930) in discarding "Papakura" in favour of "Waitemata" as a "series" name. Laws (1931) resurrected "Papakura Series" and extended its application to all Tertiary beds in the Papakura-Hunua district, including the coal measures. The latter must be considered to be unconformably below the Papakura Limestone, however, and Firth's usage is therefore adopted here.

Constituent Formations (Papakura Limestone and Mercer Beds)

Two constituent formations of the Waitemata Group have already been named—the Papakura Limestone (Hochstetter, 1864b), and the Mercer Beds (Cox, 1877).

In the present area, all the beds up to the top of the highest limestone (including much sandstone locally) should be designated "Papakura Limestone" and all overlying beds "Mercer Beds". The latter may well be capable of subdivision in the South Auckland area, but exposures in the Drury Coalfield do not favour it as the type area for such subdivision. On the accompanying map, the areas of Papakura Limestone are so small that the mapping unit on that scale is the Waitemata Group.

The bedded sandstones of the Waitemata Harbour area are, in part, of Altonian age (Finlay and Marwick, 1948, p. 24) and younger than the formations considered here.

Distribution and Content

The Waitemata Group is not known south of Ponga in the centre of the coalfield. To the north, it is exposed in the deeper gullies west of Hunua; along the Opaheke-Ponga road and northwards from there, through the Opaheke section (Symonds Stream) to Hays Stream; and north and north-east from Hays Stream, where it is the dominant rock unit through the hills south of Ardmore.

The basal shelly sandstone at Hunua Mine (N 48/m1) is probably a lateral equivalent of the Papakura Limestone, which is typically a glauconitic, flaggy, often pebbly, crystalline limestone, and is commonly separated into two or three limestone beds by calcareous sandstones and fine conglomerates. It is usually up to 10 ft thick, but reaches 30 ft in Bell Creek (Laws, 1931, p. 48).

Laws (1931, pp. 61–2) gave a petrographical description: a polyzoan limestone with some quartz, glauconite, and greywacke granules; algal in its upper part near Bell Creek, and containing Foraminifera, corals, and echinoids. Brachipods are present within the limestone (Park, 1886, p. 153) and in the overlying sandstone.

The overlying sandstone, conglomerates, and siltstones (Mercer Beds) are best exposed in Hays Stream and in road cuts, immediately east of Drury Fault (Fig. 4). An interesting boulder conglomerate in the road cutting contains greywacke boulders up to 4 ft, together with pebbles of coal measures (containing Arnold plant microfossils, Mr D. McIntyre, pers. comm.), Mangakotuku Siltstone ("foraminiferal shale"), and calcareous siltstone of the Te Kuiti Group, in a coarse sand matrix. It is overlain by an 8 ft bed of calcareous sandstone. These beds are separated from the carbonaceous sandstone and mudstone below by a 15° angular unconformity (Laws, 1931, Plate 1, Fig. 3). This unconformity is of little significance, firstly, because it diverges into three uneven surfaces along the outcrop length; secondly, because minor unconformities and contemporaneous erosion surfaces are present elsewhere in the Waitemata beds; and, thirdly, because the carbonaceous beds grade down rapidly into calcareous sandstones with minor conglomerates that resembles those above the unconformity. No bed in this sequence is of very deep water facies, and the probable minor oscillations during depositions have already been noted by Laws (1931, p. 49).

In 1956, somewhat younger beds in this group were exposed in a temporary outcrop at the Auckland City Council's filtration plant, east of Ardmore (at grid reference N 47/535375).

(a) Moderately soft, dark green-grey, very calcareous, fine-medium sandstone, with thin, light, fine-grained beds to 1 in., with comminuted shell fragments and graded bedding (N 47/f553)	6
(b) Light grey mudstone, non-calcareous, with very rare carbonaceous fragments	6
(c) Unseen	5
(d) As bed (a)	2
(e) Moderately hard medium-dark grey medium-coarse, with very much tuff (non-calcareous); and mudstone beds (very calcareous N 47/f554) which rarely have irregular bottoms and plane tops. Tuffaceous material becomes less downwards where the beds are finer (N 47/f555)	20

Age and Correlation

Pebbles in the boulder conglomerate at Hays Stream show that the Waitemata is unconformable on the Te Kuiti Group, which at youngest is of Waitakian age (Kear and Schofield, 1959).

Chapman (1926, p. 20) considered two Foraminifera from Hays Stream to be Miocene. Mr N. de B. Hornibrook (pers. comm.) has recognized Otaian microfaunas: from sandstones (N 47/f504) immediately north of Opaheke Mine (N 47/m4) and close to be the base of the Waitemata Group; from sandstone interbedded in the Papakura

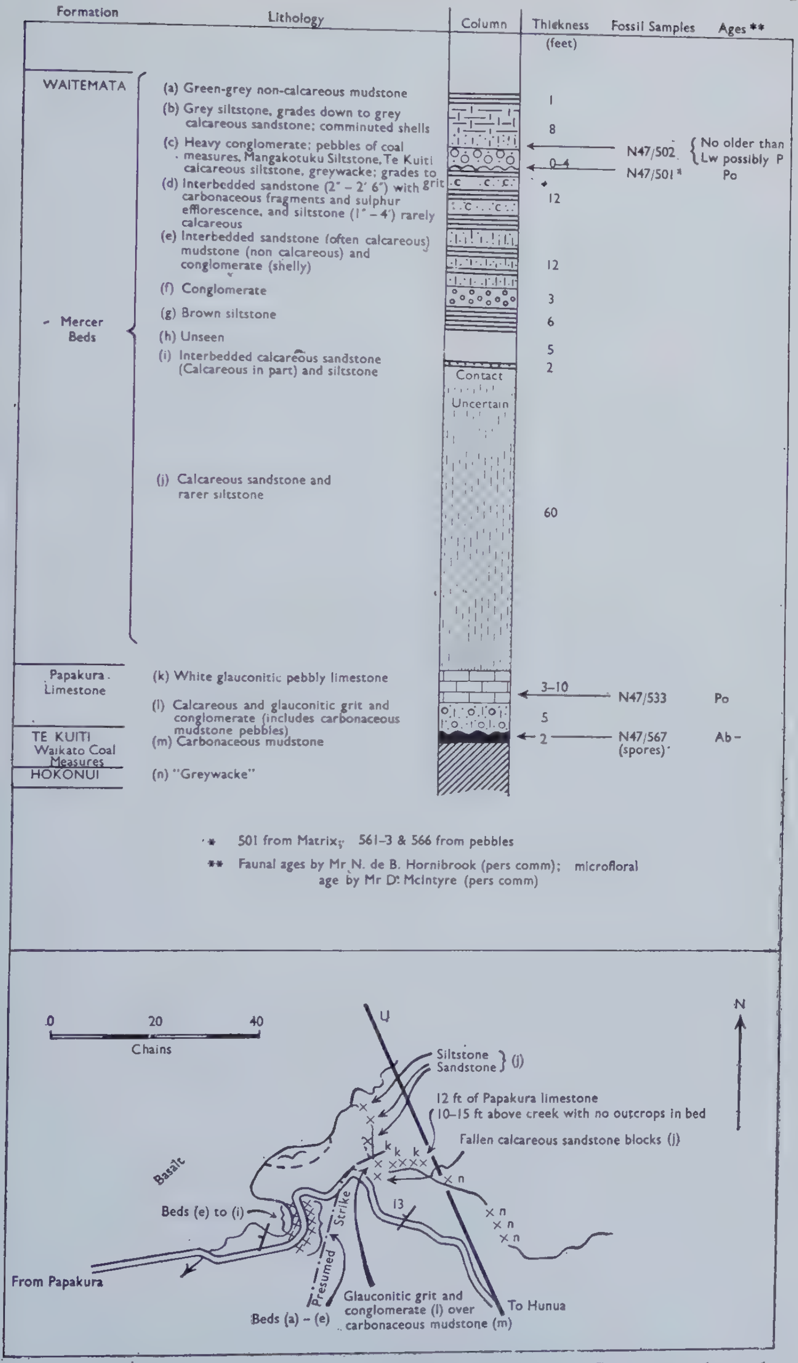

Formation
Lithology
Column
Thickness (feet)
Fossil Samples
Ages **
WAITEMATA
(a) Green-grey non-calcareous mudstone
(b) Grey siltstone, grades down to grey calcareous sandstone; comminuted shells
(c) Heavy conglomerate; pebbles of coal measures, Mangakotuku Siltstone, Te Kuiti calcareous siltstone, greywacke; grades to grit
(d) Interbedded sandstone (2" – 2' 6") with carbonaceous fragments and sulphur efflorescence, and siltstone (1" – 4') rarely calcareous
(e) Interbedded sandstone (often calcareous) mudstone (non calcareous) and conglomerate (shelly)
(f) Conglomerate
(g) Brown siltstone
(h) Unseen
(i) Interbedded calcareous sandstone (Calcareous in part) and siltstone
Mercer Beds
Contact Uncertain
(j) Calcareous sandstone and rarer siltstone
Papakura Limestone
(k) White glauconitic pebbly limestone
(l) Calcareous and glauconitic grit and conglomerate (includes carbonaceous mudstone pebbles)
TE KUITI Waikato Coal Measures
(m) Carbonaceous mudstone
HOKONUI
(n) "Greywacke"
1
8
0–4
12
12
3
6
5
2
60
3–10
5
2
N47/502
N47/501 *
No older than Lw possibly P
Po
N47/533
Po
N47/567 (spores)
Ab –
* 501 from Matrix; 561–3 & 566 from pebbles
** Faunal ages by Mr N. de B. Hornibrook (pers comm); microfloral age by Mr D. McIntyre (pers comm)
0
20
40
Chains
N
U
Siltstone
Sandstone } (j)
12 ft of Papakura limestone
10–15 ft above creek with no outcrops in bed
Fallen calcareous sandstone blocks (j)
Basalt
Beds (e) to (i)
k
k
k
n
n
n
n
13
Strike
Presumed
From Papakura
Beds (a) – (e)
Glauconitic grit and conglomerate (l) over carbonaceous mudstone (m)
To Hunua

FIG. 4.—Stratigraphic column of strata exposed in Hays Stream and roadway above, immediately east of Drury Fault. Field relations suggest that bed (j) underlies bed (i); but this is not proven, and further research must precede the publication of age determination for beds (d) to (i).

Limestone at Hays Stream (N 47/f535, Prof. A. R. Lillie, collector); and from the sandstones closely above the Hunua Mine coal seam (N 48/f526). Age determinations of the upper coarse beds (a to i, Fig. 3) in the Hays Stream and road section must await further investigation.

The Waitemata beds may be correlated generally with the type Waikawau Group of Port Waikato area, and the Papakura Limestone in particular may be correlated with the basal Waikawau limestone at Kaawa (Kear, 1957a). Sandstones, conglomerates, and limestones have been recognized elsewhere at or near the base of the Waitemata Group (e.g., at Cape Rodney, Ferrar, 1934, p. 37).

PLIOCENE-QUATERNARY SEDIMENTS AND VOLCANICS

The Pliocene and Quaternary rocks were not studied in detail. Mead (1930b, p. 313) named the Hunua Basin, where Pleistocene pumiceous alluvium and associated lignite beds rise to a height of more than 400 ft above sea-level. To the north of the coalfield, the Clevedon Depression is filled with pumiceous and other alluvium, covered locally by basaltic debris (Laws, 1931, pp. 38, 40). Similar rocks, in part as terrace remnants, underlie the lowlands west of Drury Fault (Schofield, 1958a), although there the basaltic rocks may be covered by as much as 50 ft of clay (Hutton, 1871, p. 246). Where this cover decreases, and especially where tuffs occur, the differentiation of "Basaltic Volcanics" from "Pliocene-Quaternary Sediments" is somewhat arbitrary in Fig. 2 (e.g., over large areas from Bombay north-west to Ramarama).

The basalt has been described petrographically by Laws (1931, pp. 62–3) as a holocrystalline, sub-ophitic basalt, with augite, some olivine, and large laths of acid labradorite. Healy (1935, pp. 29–31) noted that the basalts associated with the Drury Fault are coarser grained than those elsewhere in the coalfield.

STRUCTURE

MESOZOIC

Bedding is seldom seen in the Mesozoic rocks, and only two reliable dips were observed. No useful deductions can be made regarding the Mesozoic structure for the coalfield as a whole, however, because these two dips are widely different, and significant lithological changes are absent.

TERTIARY

Faults

The Drury Coalfield lies within a region of Kaikoura Orogeny block-faulting. The 170°-striking western boundary fault (Drury Fault, Figs 1, 2) is the most significant. Its large westerly downthrow is shown topographically, and by drilling. Holes in the area ½ to 1 mile north-west of Stevenson's Quarry have failed to reach Hokonui rocks at a depth of 700 ft (Mr G. E. Nairn, pers. comm.). A deep hole drilled by Mr G. H. Gilberd at Karaka (N 47/414276), 5 miles west of the fault, cored calcareous sandstones with an upper Pareora to Southland microfauna (N 47/f525) at 530 ft; but Hokonui basement had not been reached when the hole was completed at 2,016 ft. Mr N. de B. Hornibrook (pers. comm.) examined cuttings that had definitely been contaminated by drilling mud, and could theoretically have included caved material from higher parts of the hole. He considered that a lithological change took pace between 1,930 ft (N 47 f527) and 2,0162 ft (N 47/f531), with the Mangaorapan-Heretaungan form *Truncorotalia crater* appearing in the lower sample. This suggests that Ferrar's (1934) Onerahi Beds of the Dargaville-Rodney Subdivision extend southwards beyond Auckland, an inference that is consistent with Park's (1886, p. 156) record of "large masses of hydraulic limestone" within Waitemata beds on the northern side of Manukau Harbour at Whau Bay, and with Healy's (1935, p. 7) record of Onerahi limestone fragments in basaltic tuffs immediately north of Maketu Stream and 2 miles east of Ramarama. The possibility of contamination of Mr Hornibrook's material, however, precludes any definite inferences at this stage.

Against this strong evidence for a large throw on Drury Fault are local reports of "greywacke" and "rotten rock" at shallow depths near Opaheke, and Laws's record (1931, p. 59) of coal below basalt in a bore near Drury. Possibly, a wide fault zone is present.

Apart from the major Wairoa (Mead, 1930b, pp. 310-1) and Pokeno (Bartrum and Branch, 1936, p. 387) faults that strike at 170° and 060° to the east and south of the coalfield respectively, only the Hunua Fault (Laws, 1931, pp. 57–60) is well established within the coalfield. Other faults trend north-north-east or north-east, but the unevenness of the pre-Tertiary surface makes their strikes, and even their presence, uncertain. A small normal fault in the Hays Stream road section strikes at 060° and downthrows the beds to the south by 10 ft, and another normal fault at Sevenson's Quarry strikes 135° (fault-plane dip 50°).

Dip

The Tertiary beds generally dip west. Thirteen scattered dip observations ranged from 8° to 20° towards 240° to 300°, and dips outside these limits are relatively few. Those that are anomalous are frequently close to the basal Tertiary contact, presumably as a result of uneven compaction above the irregular depositional surface, although south-south-west dips were measured in the Hingaia Stream section, and a gentle east-north-east dip appears general in the Hunua Mine area.

RELATION OF STRUCTURE TO VOLCANISM

Mead (1930b, pp. 310–1) pointed out that volcanic rocks are rare and andesitic to the east of Wairoa Fault, but common and basaltic to the west of it.

Figure 2 shows a number of areas of basaltic rocks that clearly have been erupted from many individual centres. Some centres are so close to Drury Fault, and aligned so nearly parallel to it, that it may reasonably be inferred that the basalt was extruded up the fault plane as Bartrum and Branch (1936, p. 389) have suggested. Other basaltic eruptions are clearly related to mapped faults.

The basalt eruptions probably post-date the major faulting movements since: (1) the Kaawa Formation of the West Auckland Coast was unaffected by the earth movements that faulted the underlying Waikawau Group (Kear, 1957a); (2) even the oldest of the pumiceous "Pliocene-Quaternary" sediments of the Drury area are unlikely to be older than the Opoitian Kaawa Formation (Marwick, 1948); (3) the basalts appear to overlie at least some pumiceous beds of the Papakura-Bombay and Pokeno lowlands (Laws, 1931, p. 40; Kear, 1957b; Mr G. E. Nairn, pers. comm., re drillholes north-west of Bombay); and (4) either the earth movements (Kaikoura Orogeny) at Kaawa and Drury were probably nearly contemporaneous or those at Drury were older (Marwick, 1948). Fyfe's (1933, pp. 203–5) evidence of post-basalt faulting is not considered to be conclusive, as crushing and slickensiding were noted only in Hokonui rocks.

ECONOMIC GEOLOGY

Coal

History, Output, and Coal Thickness

Coal was mined at Drury intermittently from 1859, when the Waihoihoi Mining Co. commenced operations, until 1935, when the last mine closed in Symonds Stream valley. There have been four distinct coal-mining sections: "Drury", in the hills south-west of Drury settlement, immediately north of Stevenson's large greywacke quarry; "Bombay", on the northern slopes of Puketutu hill; "Hunua", in the rolling country 1½ to 3 miles west and south-west of Hunua settlement; and "Opaheke", in the valleys of Symonds Stream and its tributaries (e.g., especially near where the old Opaheke-Hunua track crosses the stream on Browne's or Fraider's freehold).

Table 2, compiled mainly from New Zealand "Mines Statements", shows the names, locations, seam thicknesses, years worked, and outputs for the 11 mines, and leaves little doubt as to the worth of the coalfield. The average seam thickness was 4 ft, of which only about 3½ ft was workable, the average mine life was under 3 years, and the average output for the whole life of a mine was only about 750 tons.

Seams up to 15 ft in thickness have been recorded in drill-holes (e.g., at Drury Mine), but have never been substantiated in mining operations.

Areal Extent

Many coal outcrops have been located in the Drury, Hunua, and Opaheke mining areas, where continuity of seams is presumed in spite of the unconformity below the Waitemata Group. The holes drilled by Mr Nairn through coal measures (see logs above) showed 4 ft and 3 ft of coal at Bombay and Hunua respectively in probable virgin blocks, and 2 ft 9 in. of coal was exposed on Mr Reid's property a mile down the road towards Ponga from the Hays Stream Valley road to Hunua. Elsewhere, relatively little is known of the areal extent of the coal, as the rocks are seldom exposed at the coal horizon. No seam of reasonable thickness was included in the coal measure strippings off Stevenson's Quarry. Laws (1931, p. 64) recorded 2 ft of coal only in Hays Stream, at an outcrop that could not be re-located in the recent fieldwork. He also stated that a drill-hole in the Ardmore Valley area had found only 4 in. of coal and that this had "disposed of all hope of the coal attaining sufficient thickness to be valuable commercially" (p. 64).

Quality

Table 3 presents 20 of the more reliable of some two dozen analyses of coal from the Drury Coalfield grouped under each of the four mining sections. The variations in individual values are considerable, and are probably due to the thinness and dirtiness of the seam, and to the lack of fresh underground samples. The average of all samples (air dried) approximates to:

Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Calorific value
18%	34%	36%	12%	1%	8,900 B.t.u./lb

The bed moisture is uncertain, but the coal is probably close to the boundary between the Sub-bituminous B and C ranks of the A.S.T.M. classification. On an ash-free basis, the calorific value averages 10,000 B.t.u./lb, and on a dry, ash-free basis 12,700 B.t.u./lb.

The high ash content is significant, and no doubt was a major factor (together with the thinness of the seams) in keeping down the coalfield output. The sulphur content is low, but it might have been higher had completely unweathered samples been collected at the working faces of the mines. Its average value, $\frac{1}{2}$%, in the Hunua area is particularly significant, since Waitemata Group marine beds are only a few feet above the coal seam. If no unconformity existed between them, a much higher sulphur content would be expected (compare the higher sulphur contents, 1% to 5%, in Greymouth coals ranging 150–10 ft below marine beds: Wellman, 1952, pp. 98–102, Plate XVIII, Fig. 3).

TABLE 3.—The More Reliable Proximate Analyses for the Four Mining Areas of the Drury Coalfield.

Field No.	Lab. No.	Date	Moist. (%)	Volatile matter (%)	Fixed carbon (%)	Ash (%)	Sulphur (%)	Calorific value (B.tu./lb)	Locality and remarks
					DRURY AREA				
N47/a11	150	1905	14·5	41·1	35·6	8·9	0·41	—	Drury, probably Drury Mine
N47/a13	N/2999(2)	1922	13·15	44·85	34·8	7·2	0·48	—	"Drury"
N47/a16	—	pre-1882	14·0	35·0	42·0	9·0	—	—	Waihoihoi Mine (Cox, 1882, p. 33)
N47/a202	CS5264	1950	21·9	29·0	46·9	2·2	1·0	9,510	4 in. seam near Drury No. 1 Mine
Average Drury	—	—	15·9	37·5	39·8	6·8	0·6	9,510	
					BOMBAY AREA				
N47/a8	4528	1887	20·20	23·57	38·02	18·21	—	—	J. Park, Collector
N47/a9	4884	1888	20·02	29·77	44·00	6·21	—	—	"Bombay"
Average Bombay	—	—	20·1	26·7	41·0	12·2	—	—	—
					HUNUA AREA				
N47/a1	0/3310	1923	20·90	38·60	34·30	6·20	0·41	—	Cowans Mine
N48/a6	4825/1	1888	18·33	28·64	42·81	10·22	—	—	A. McKay, Collector
N48/a7	4825/2	1888	20·12	28·36	34·68	16·84	—	—	A. McKay, Collector
N48/a8	A/261	1910	15·37	44·61	33·52	6·50	0·30	—	"Hunua"
N48/a9	V/2525	1930	23·07	30·65	43·42	2·86	0·51	—	"Hunua District"
N48/a11	K1827(4)	1919	18·96	40·11	32·19	8·74	0·95	8,885	Probably Hunua Mine
Average Hunua	—	—	19·4	35·2	35·2	10·2	0·5	8,885	

OPAHEKE AREA

N47/a3	—	pre-1931	18·12	32·31	31·75	17·82	1·97	—	Laws (1931, p. 63; possibly near mouth of Opaheke Mine
N47/a4	—	1950	19·2	29·1	33·3	18·4		8,162	Near mouth of Glendale No. 1 mine
N47/a5	—	1950	16·7	36·6	34·8	11·9	—	8,364	
N47/a6	—	1950	18·3	31·1	35·8	14·8	—	8,754	Symonds Stream outcrop near Glendale No. 1 Mine mouth
N47/a7	—	1950	22·2	29·2	44·0	4·6	—	10,720	
N47/a14	0/358	1923	17·65	34·45	31·95	15·95	0·44	-	"Papakura, Opaheke". Probably Opaheke Mine
N47/a201A	CS5262	1950	16·2	31·5	30·8	21·5	1·7	7,540	1 ft 10 in. seam near N47/a6–7
N47/a201B	CS5263	1950	16·1	38·2	33·7	12·0	0·5	9,360	2 in. seam
Average Opaheke	—	—	18·1	32·8	34·6	14·5	1·2	8,800	
Av. Drury Coalfield	—	—	18	34	36	12	1	8,900	

Analysts: All samples analysed by Dominion Laboratory (see Annual Reports) except N 47/a3 (by Wilson Cement Co.) and N 47/a4–7 (by Thames School of Mines—Mr H. Crawford).

Prospects

There is little prospect of large mining operations in the future. All seams are likely to be less (possibly substantially less) than 6 ft in thickness, to contain more than 10% of ash, and to be interbedded with bands of carbonaceous mudstone. Any future mining seems destined to be on the same small scale as in the past, although coal might prove a useful by-product in clay workings.

No estimates of recoverable coal can reasonably be made.

CLAY

Clay is likely to prove of greater economic significance than coal.

Weathered Mesozoic greywackes found at many places in the coalfield are probably suitable raw materials for the ceramics industry. Locally, the weathering has proceeded to a plastic white clay showing little or no remnants of the original rock structure (e.g., joints) in the hand specimen (as along the road leading southwards from Dunns Road to the Bombay-Paparata Road). No field or laboratory investigations have yet been conducted into the suitability for ceramics of weathered greywacke in this area.

Fireclay has already been worked in conjunction with Drury Mine, where the coal was used largely in the company's brick kilns. Laws (1931, p. 63) quoted an analysis of fireclay from the Opaheke mine area:

	%
Loss on ignition	7·44
Silica	46·94
Alumina	38·12
Oxides of iron	Trace
Oxides of zinc	Trace
Magnesia	Trace
Sulphur trioxide	0·43
Alkalis and undetermined	7·07

The reserves of fireclay are uncertain, but some recent excavations between the coal seam and the greywacke near Waihoihoi Mine showed that little useful material can be expected there, even below the coal seam where the most refractory material is likely to be found. The top of the greywacke is well leached, but sandy; and the 25 ft of beds up to the coal seam are mostly too sandy or carbonaceous to constitute a useful fireclay.

Carbonaceous mudstones above the coal seam are of even lithology and locally more than 100 ft thick. Two to three miles east of Ramarama, a reasonably extensive deposit of mudstone caps ridges along which the roads have been constructed. No detailed drilling programme has yet been undertaken, but the order of reserves is 5,000,000 to 15,000,000 cu.yd. Small deposits no doubt exist elsewhere (see Fig. 2), but the next most useful deposit may well be that crossed by the Opaheke-Ponga road, 2 miles from Opaheke.

Other clays that appear to be less suitable materials are the "foraminiferal shales" of the Mangakotuku Siltstone, which are about 100 ft thick, and basaltic clays which are of far less uniform thickness.

ROAD METAL AND AGGREGATE

Although the Mesozoic greywacke is usually severely weathered, good quarry sites are available on the upthrown side of Drury Fault scarp (e.g., Stevenson's Quarry) and in the steeper creek valleys (e.g., Hays Stream). Elsewhere, where the topography is not steep, suitable sites are unlikely.

Basalt has been quarried, for example, at the point where Hingaia Stream crosses Drury Fault. Quarries in basalt, however, are more likely to reach poor quality stone (e.g., tuff beds and highly weathered joints) than are those in greywacke, and will always be of subsidiary importance.

GLASS SANDS

Seelye (1923), in a paper on New Zealand glass-sands, quoted two analyses of highly siliceous sandstones (96 to $97\frac{3}{4}\%$ SiO_2) from Bombay. He noted that the degree of coherence was unknown. However, the samples were probably from the basal beds of the coal measures (Bartrum and Branch, 1936, p. 399), and therefore the cohesion would probably be too great for their economic use as glass sands.

LIMESTONE

Aston (1918, p. 99) gave analyses for the Papakura Limestone that averaged 84% at Clevedon and 88% at Papakura (Hays Stream). However, the difficulties of thinness and of interbedded calcareous sandstones suggest that the limestone will never be worked economically on a large scale as a source of agricultural lime.

MANGANESE

Fyfe (1933) gave a detailed description of a manganese deposit at Bombay (N 48/566197, Fig. 2). He recorded the presence of 1,000 to 8,000 tons of ore, and gave analyses of grab samples of "high grade ore" from there as 78·7% to 82·2% MnO_2 and 5·24% to 42·5% MnO. Small pockets of manganese ore are well known in the Hunua ranges, and other deposits may be present within the area of Fig. 2.

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THE VOLCANOES OF IHUMATAO AND MANGERE, AUCKLAND

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Summary

The volcanic features of the Mangere-Ihumatao district, near the city of Auckland, are described and their relative ages and eruptive histories discussed. In all cases eruptions in the area occurred during the period of the Flandrian transgression, before sea-level had attained its present height and at Mangataketake have been dated by radiocarbon as occurring 29,000 ± 1,500 years ago. The location of craters associated with individual centres shows marked distribution along lines trending north of north-north-east.

INTRODUCTION

It is quite obvious from his writings that Hochstetter did indeed find the volcanic features of the Auckland isthmus a fruitful field of "geognostic observation"* and that he was fascinated with the array of almost miniature cones and craters—"volcanoes on the smallest scale . . . perfect models of volcanic cones and crater formation"—"promiscuously scattered over the isthmus and the neighbouring shores of the Waitemata and Manukau harbours" which he describes as "one of the most remarkable volcanic districts of the earth". Possibly no other portion of his work in New Zealand has carried for so long the seal of approval as has his almost lyrical description and explanation of this field, for it remains to this date the only comprehensive published account of the volcanoes of the area. His careful mapping of the field and his sketching of many of its features will long remain a record of value, though many of his explanations and much of his theorizing have become outmoded as more evidence has accumulated.

Hochstetter pictured the ideal Auckland volcano as three-tiered, "with a tuff-cone forming the basis and pedestal of the whole structure; a lava cone, the chief mass of the mountain and a scoria cone forming the top of the mountain," and he looked upon the structures as built separately in that order. Whilst some of the local hills conform more or less to this pattern, there can be no doubt that in the majority of cases the lava aprons that surround them have been formed contempor-

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*Quotations are from Hochstetter (1867).

N.Z. J. Geol. Geophys. 2 : 870-88.

aneously with the building of the scoria cones as, indeed, he recognized (p. 232) although his illustration (p. 238) would suggest otherwise. Similarly, a wide explosion crater with its encircling tuff ring is certainly not evident at the base of a number of the cones and its presence as an essential element of the structure need not necessarily be inferred.

Hochsetter seems to have been intrigued in particular by the several local examples of tiny scoria mounds encircled by the ramparts of a large tuff ring, and instances Waitomokia (Gabriel Hill) as perhaps the most perfect example of this kind. He noted among such volcanoes a continuous series with examples ranging between the extremes of Pupuke, with its wide crater devoid of scoria cone and occupied by a fresh water lake nearly 300 ft deep and of Mt Wellington and Purchas Hill, where the twin scoria cones have been upbuilt to overtop and largely embrace initial tuff rings. He saw in these features a refutation of von Buch's theory of elevation (which has long since been discredited) and explained the smallness of the many central scoria cones within tuff rings "by later sinking down, by a sagging of the cinder cone within its tuff-enclosure, by which even cones that had towered high above the tuff crater, sunk into their topmost points, some of them perhaps disappearing entirely". It is true that in some few instances there is evidence of collapse in the floors of caldera (e.g. possibly at Papatoetoe Crater) but this is certainly not so in the majority of cases; it is difficult to understand why such an astute observer as Hochstetter should invoke so involved an explanation of rather obvious relationships.

In these days, too, geologists would find it difficult to accept completely a sequence of eruption at individual centres such as was postulated by Hochstetter. He considered that initial eruptions, producing tuff cones and explosion craters, were probably submarine and took place at the bottom of a well-sheltered bay. He was almost certainly led to this conclusion both by the present elevation of many craters with respect to sea-level and also by the finely stratified nature of the gently dipping (5° to 10°) tuff beds that surround them. It is now known that the majority of local eruptions took place during times of low sea-level and that many craters now situated near sea-level were formed in areas then far removed from the sea. The fine bedding in the tuffs would now be attributed to showers of debris from intermittent explosive blasts with intervening intervals of relative quiescence that permitted the settling of fine ash.

Hochstetter recognized clearly that the scoria cones were subaerially formed and was therefore forced to deduce that "with the beginnings of the volcanic activity [there] seems to have commenced, although very gradually, a rise of the whole isthmus; so that later eruptions took place above the sea." In this terrestrial period of volcanicity "red hot masses of scoria and streams of lava" built up the main volcanic piles. For many reasons an hypothesis requiring eruption in two phases, the first submarine and the second supramarine, is wholly unsatisfactory. It is now known that activity was initiated at different centres at different times extending over a period of more than 40,000 years, yet the hypothesis would demand essentially contemporaneous eruption at the various centres, followed by a time lapse sufficient for the elevation of the isthmus, and then resumption of activity at the same centres.

These criticisms, made in the light of later knowledge, in no way detract from the value of Hochstetter's work. He has left an excellent catalogue of the volcanic centres as seen before the advent of the city, and a record of many features that are no longer accessible to the modern worker. And he has left, impressed in his writings, an infective appreciation of this unique field where "volcanic activity seems to have made itself a new way nearly at every eruption and has thus splintered into a number of small cones, while by always keeping one and the same channel it might perhaps have formed one mighty volcanic mountain" (p.230).

GEOLOGY OF THE DISTRICT

The volcanoes to be described in this paper are located at the northern end of the Manukau lowlands—a depressed earth-block, separated from the Auckland peninsula by the inferred Manukau fault, and from the highlands to the east by the Papakura-Drury fault and its inferred continuation north of Papakura Valley. The terrain is constituted of sediments of the Waitemata Formation (Altonian) covered with the less well consolidated sandstones, mudstones, and shell beds of the Otahuhu Formation of Pliocene age. Over the Tertiary strata is a sheet of pumiceous silts, sands, and peat beds which Hochstetter (1864) referred to his Lignite Formation. The carbonaceous beds that occur are more typically peats than lignites and it is unfortunate that, in defining the formation, Hochstetter (1864, p. 50) should have made particular reference to the timber-packed beds of Tamaki estuary north of Panmure Bridge. Radiocarbon dating by Ferguson and Rafter (1959) fixes the age of this particular bed as 28,000 ± 1,000 years before the present, but it may be accepted with some degree of certainty that the majority of the pumice silt beds and their associated peats and plastic clays are much older. Searle (1959a) has advanced evidence indicating that they antedate the formation of the 100 ft terrace and has suggested the name Whau Formation for similar sediments in the Waitemata basin. A layer of volcanic ash, varying greatly in thickness and fanning out from the various centres that produced it covers the whole area, and above it rise the small scoria mounds and their associated lava flows that mark some of the centres of eruption.

Within the area covered by the map, Fig. 1, Pleistocene silts are exposed at the surface in a cut-terrace at 7 ft to 8 ft above M.S.L.,

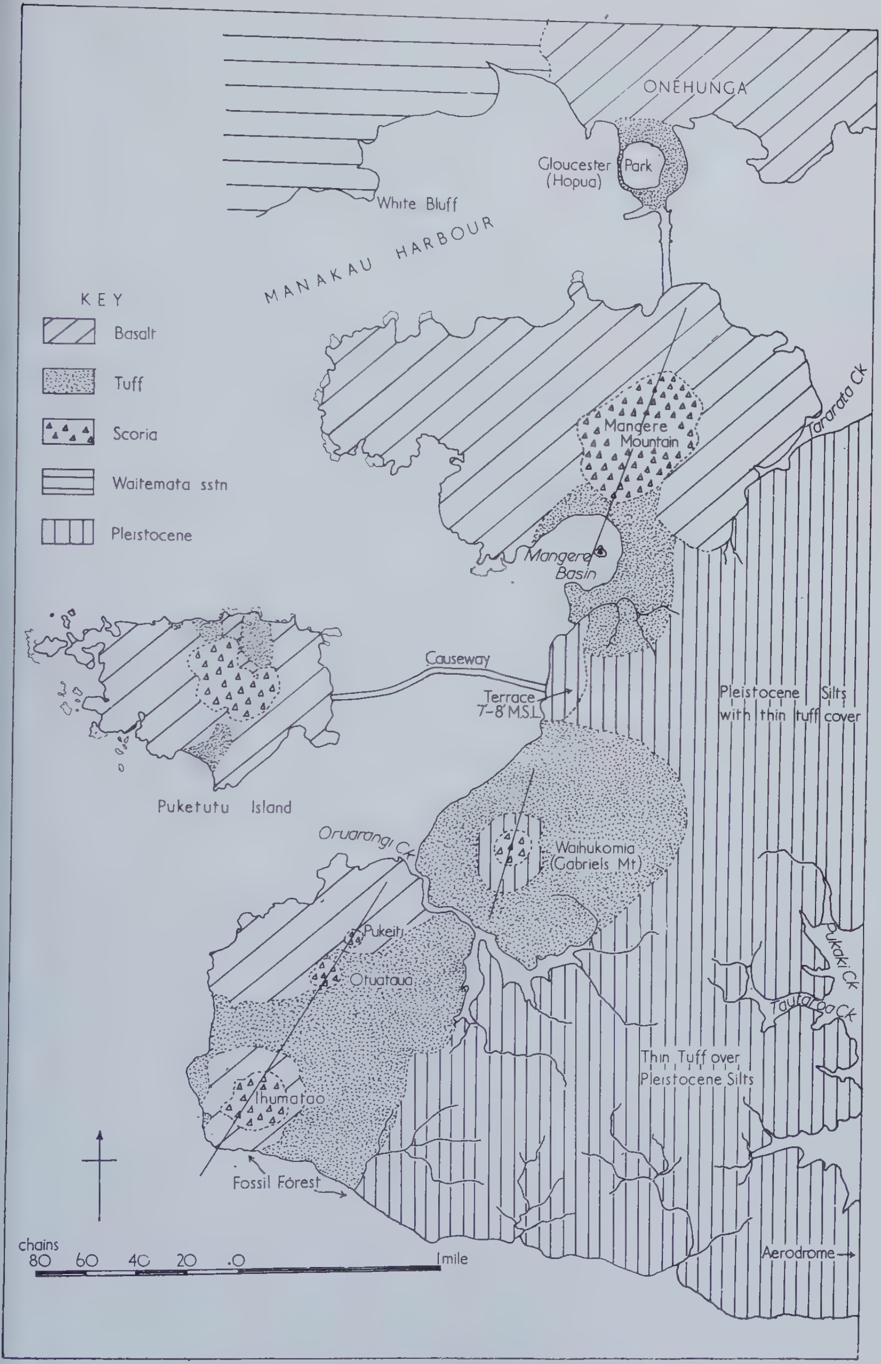

FIG. 1.—Geological sketch map of the Mangere-Ihumatao District showing lines connecting associated vents in particular centres.

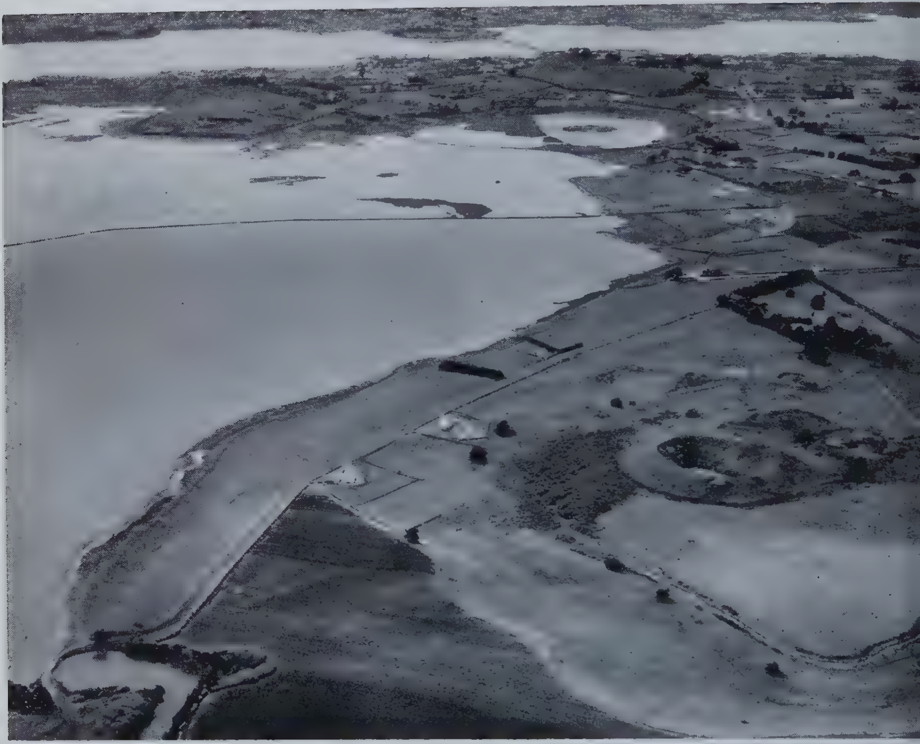

Fig. 2.—The tuff crater of Waitomokia with central scoria cones and explosion pits in tuff ring. Beyond, note low terrace cut in Pleistocene silts, and in the middle distance the explosion crater of Mangere Lagoon with Mangere Mountain behind. In the far distance, on the right is White Bluff and in the centre, Onehunga Basin (tuff crater).

Photo: Whites Aviation.

clearly shown in the aerial photograph (Fig. 2). Its formation is probably referable to the maximum rise of sea-level during the Flandrian transgression and it may be regarded as equivalent to other low built terraces noted by Searle (1959b) on the shores of Waitemata Harbour. A sewage treatment plant is in course of construction on this terrace which has, in consequence, been explored by a large number of drill holes sunk to varying depths by the Auckland Metropolitan Drainage Board. The log of bore hole No. 245, typical of the records of many other holes, is set out below:

R.L. of surface 7·07 ft
soil and peat.
4 ft
iron-stained tuffaceous sandy clay.
2 ft
peat.
M.S.L. 0
Pumiceous silts.
2 ft below M.S.L.
Peaty clay.
4 ft below M.S.L.
Clay with some carbonaceous matter.
12 ft below M.S.L.
Peaty clay and some wood.
13 ft Below M.S.L.
Firm sandy clay and plastic clays.
20 ft below M.S.L.
Unconsolidated sands.
22 ft below M.S.L.
Soft sandstone.
36 ft below M.S.L.
Firmer clay and sandstone.
41 ft below M.S.L.
Shell sands.
54 ft below M.S.L.
Peat.
57 ft below M.S.L.
Clay silts.
64 ft below M.S.L.
Soft sandstone.
76 ft below M.S.L.
Shell beds.
85 ft below M.S.L.
Bottom of hole.

This terrace would appear to have been cut after ash had been spread over the Pleistocene silts by eruptions from Mangere Lagoon, since the northern portion of the surface is cut into the flank of the tuff ring. Eastward of the terrace the thickness of the ash cover varies from 2 ft to 8 ft and in places it directly overlies beds of peat. In deep trenches and tunnels nearby peat beds with intercalated silt members amounting to approximately 20 ft in thickness are exposed. At Glendowie on the northern side of Tamaki inlet similar measures outcrop at altitudes of more than 100 ft above M.S.L. These beds are substantially horizontal and undisturbed so that it may be inferred that nearly 100 ft of sediments have been removed by erosion from the northern section of the Manukau lowlands prior to the spreading of volcanic debris over their surface.

It will be noted in the record of bore No. 245 that shell bands were encountered at approximately 40 ft to 50 ft below M.S.L. and again at about 80 ft below the same datum. Firth and Page (1936) recorded similar beds at 67 ft and at 95 ft to 97 ft below M.S.L., in wells sunk at the north-eastern foot of Mangere mountain and these beds have been inferred by Marwick (1948) to be of the same age as the lower Pliocene shell beds of his Otahuhu Formation. In the Mangere well, as in the present bores, the upper shell bed is underlain by peats, which Marwick regards as compatible with the shallow water facies indicated by the Otahuhu faunule. In the A.M.D.B. bores the shell beds were encountered at a higher level (top of the bed at — 41 ft M.S.L. as compared with — 95 ft for the auxiliary and — 67 ft for the main well at Mangere), and at approximately the same altitude (— 46 ft) as the beds at Otahuhu. Schofield (1958) refers all the Pliocene shell beds of the Manukau lowlands to the Kaawa Formation and records such beds as occurring at depths as great as 200 ft below sea-level. It seems likely, as Marwick (1948) has suggested, that the shell beds are local and lenticular beds and this suggestion finds support in their occurrence at various levels in the Mangere bores.

On comparison of the Mangere bore logs with the log of the Otahuhu well it would seem reasonable to regard the firm sandy clays at 13 ft below M.S.L. and below the 1 ft bed of peaty clay and wood as being the uppermost beds of the Pliocene sequence, and to regard as Pleistocene (Lignite Formation) only the sediments that occur above that horizon. The implication is, that here, as at Otahuhu, the Pleistocene sediments form a relatively thin upper section of a conformable body of Pliocene-Pleistocene deposits.

THE CENTRES OF ERUPTION

The main features of the volcanoes of the northern part of the Manukau County have been described by Firth (1930); it is proposed here to add the results of more recent detailed investigation. Apart from the group of vents forming Puketutu Island, the centres are disposed in a distinctly linear fashion about a line trending N.N.E. That this direction has some genetic significance, as will be elaborated later, is highly likely, but in a field such as Auckland the value of such lines established by connecting other than clearly related centres must be considered as doubtful, for with numerous, more or less evenly-spaced centres many linear arrangements are possible. In the present case, for example, if adjacent centres, outside the area mapped in Fig. 1 be included, a number of different lines may be drawn so that each passes through three or more centres.

Waitomokia (Gabriel Hill)

In the middle of the group is Waitomokia (Gabriel Hill), Figs 2 and 3, with a wide explosion crater about half a mile in diameter, surrounded by a low tuff ring of light-grey fairly well consolidated tuff consisting of comminuted sedimentary material, blocks of partly baked sediments, fine ash, and other juvenile volcanic debris. Much of the material is stratified in thin beds of lapilli in a matrix of fine ash, whilst

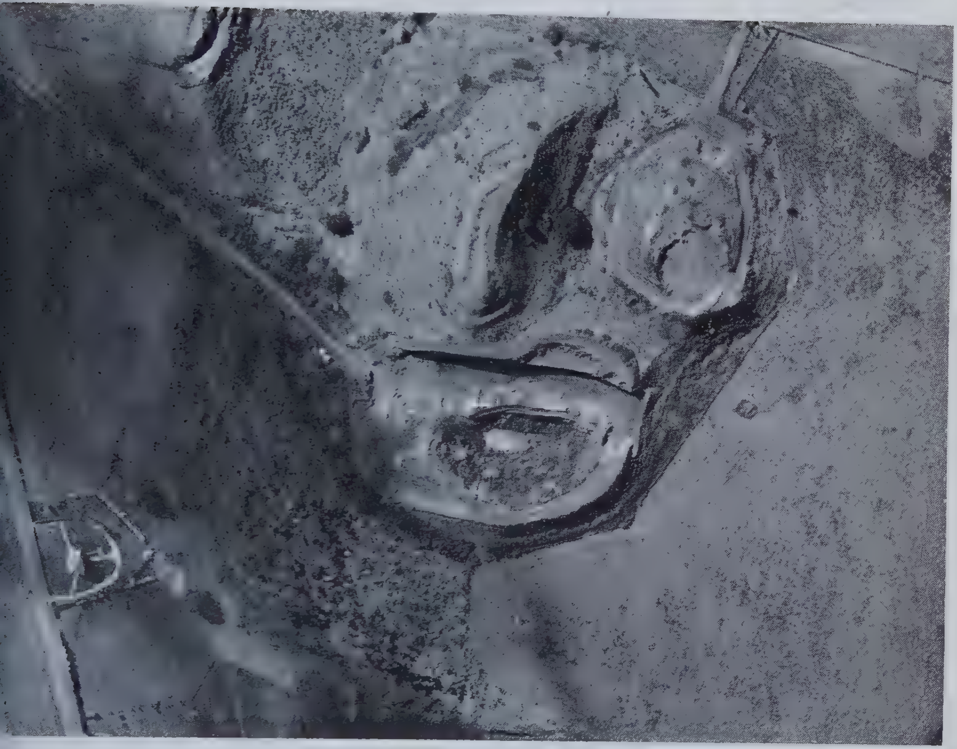

FIG. 3.—The three central cones of Waitomokia in 1958 (two years later than Fig. 2) showing the rapidity with which these features are being destroyed.

Photo: Whites Aviation.

close to the crater and in the higher parts of the ring the tuff is poorly sorted, has ill-defined stratification, and contains many large blocks. The explosion ring is roughly oval in shape and the western flank is cliffed on its inner margin. The floor is flat, with swamp deposits filling it to 20 ft above M.S.L., and in the centre of the crater is a group of three small scoria cones that barely rise above the crest of the higher portions of the ring.

It is unlikely that this wide and shallow crater could have been produced by explosions from any single vent. Embayments in the perimeter of the crater point to a number of closely spaced centres of eruption whose combined activity would explain both the size of the basin and the fact that it is so shallow—the debris from later explosions tending to fill in the small craters of earlier ones. It is probable that most of the large tuff rings of Auckland were similarly formed by explosions from a number of centres in a group, just as many of the scoria cones were built by more than one vent; multiple vents are just as likely to produce a near circular crater as a single one. However, the evidence of a series of explosive eruptions separated in time as well as in position is clearer at Waitomokia than in most other cases, for here a line of small explosion craters lies across the north-east section of the tuff ring and they have obviously been blasted through the earlier tuff accumulation (see Fig. 2). There is fairly clear evidence of at least 7 or 8 explosive vents, indicated either by embayments in the outline of the crater or by definite pits; it is probable that even more small centres were active on the floor of the crater but have been filled in or covered over by the debris of later eruptions.

The scoria cones are composed of the coarse slaggy products of fire-fountaining but there is no evidence of lava flows and if any such were formed they must have been contained within the tuff ring and now lie buried beneath the alluvial and swampy fill. Only the westerly cone of the group has a crater and this is elliptical in outline with a narrow swampy base at about the same level as the floor of the main explosion crater. The northerly cone is slightly crescentic in cross-section and appears to be a flanking remnant of an earlier cratered cone which has been destroyed by explosive eruptions associated with the opening of later vents. The third cone may also be a remnant of this older structure or of another early-built cone. The symmetry of the system suggests that the westerly unit was the last to be built and it may well be that the initial eruptions that culminated in the short-lived episode of fire-fountaining, by which it was produced, were responsible for the destruction of the former scoria cone. However, this explanation is not wholly satisfying, as the direction of elongation of the crater of the younger cne lies athwart the rupture between the other two, and vigorous quarrying during the last two years, which has almost completely eliminated two of these cones and doubtless within a short time will cause the whole group to vanish from the landscape, has revealed differences in constitution of the cones that support the contention that they are all separate units built by different vents.

The topographic form, the constitution of the tuff and scoria accumulations, and the large number of explosion pits associated with this small volcano draw attention to the complex eruptive patterns of even very minor centres. The scoriaceous slag and abundant lapilli in the tuff indicate a measure of activity of the fire-fountaining type even during phases of eruption which were dominantly phreatic, and the existence of craters in the tuff ring suggests explosive episodes late in the history of the centre. Although it need not necessarily be so, the whole picture is not incompatible with a history of activity recrudescent over a much longer period of time than is generally assumed for the building of such minor volcanic structures. The distribution of individual vents in the volcano shows a distinct linear disposition along a line trending east of north. It is felt that much more significance may be attached to linear distribution between the vents of particular systems than may be to lines linking the less intimately related centres in the field as a whole. At Waitomokia the distribution of vents clearly suggests activity along a N.N.E. rupture, eruptions at the northern end of the line being later than those at the southern end.

The tuff surface dips outwards from the crater at a low angle to the shore where thinly bedded and well cemented tuffs are exposed in a wide cut platform. In the south, they continue across Ourangi Creek and pass under massive basalt flows from Pukeiti. It may be accepted, therefore, that activity at Waitomokia antedates that at Pukeiti.

In his map, Hochstetter (1864) shows two further large tuff craters with swamp-filled bottoms to the north-east of Waitomokia. This is clearly an error, for boring on the area shows that the ash cover is quite thin and diminishes in thickness as the distance from Waitomokia increases. It is probable that he mistook low swampy areas formed behind tuff accumulations for explosion craters.

Pukeiti

The flows of Pukeiti appear to have been outpoured freely and to have flowed mainly in a northerly direction from their vent. Effusion was accompanied by a minimum of other types of activity, except at one point where fire-fountaining of very short duration threw out coarse clots of slaggy basalt that built up a low dumpy cone to a height of about 30 ft above the lava surface. This cone has a shallow saucer-shaped crater of 15 ft to 20 ft depth and appears to have been built of lava splashes rather than by normal fountaining; its building was probably a near final event in the activity at the centre. It is unlikely to have been the main source of the lavas that constitute the field; the principle site of extravasation was possibly near a steep lava ridge to the north of the cone, built up to approximately the same height as the cone, and showing considerable collapse and evidence of gas fluxing.

Three main lava streams may be distinguished in this small lava field. The oldest lies to the north-east and its lavas appear to pass under the flows emanating from Otuataua and thus fix the relative ages of these two centres. A second flow, to the north-east, is characterized by major collapse features along its southern flank showing large lava slumps backed by scarps formed where marginal solidified crust has broken away. Escape of lava at a low level in the advancing front of the flow caused large areas to collapse near the toe and induced minor collapse along the crest of the flow, resulting in a depressed furrow along its length. The main and latest outpouring was to the north and produced sinuous streams radiating from the principal vent. The lavas of this volcano are thinly coated with ash which smooths the relief of the micro-topography and makes the area suitable for pasturage. In this respect the lava field of Pukeiti contrasts markedly with that of Otuataua where the lavas are for the most part bare of ash. It is clear, therefore, that explosive eruptions in the area, later in date than those of Waitomokia, intervened between the extravasation of the lavas of Pukeiti and those of Otuataua.

Otuataua

Eruptions at Otuataua were more varied and on a larger scale. Explosive eruptions near at hand and farther south near Mangataketake produced much tuff but the deposits from different centres have so interfered one with another that it is no longer possible to differentiate clearly between the constructional forms of individual vents. The result is a group of poorly defined, smoothed ridges with craters obscured and incomplete. Appearances suggest that the scoria cone of Otuataua has been constructed near the rim of one large tuff cone which is now covered to a large extent by flows from the centre. Otuataua, then, is younger than Pukeiti and most of the adjacent tuff accumulations, though, no doubt, minor explosive eruptions occurred in the vicinity after the effusion of lava from the main centre. One such is indicated by an elliptical explosion pit to the south of Otuataua; it is a small crater with a flat swampy bottom. Its smoothed profiles suggest partial infilling by tuff from other eruptions.

The cone itself is steep-sided with a small shallow crater breached to the north-west, whence radiates a fan of lava. It is suggested that vigorous fire-fountaining accompanied effusion at the vent and piled up the cone at the back of the fountaining vent while the lava of the flow rafted away material thrown to the north-west and so prevented the forming of a symmetrical cone with a summit crater. Certainly the main outpouring of lava was from the flank near the base of the cone. A later explosive eruption at the base of the cone on its south side, and on the margin of the flow, made a deep though small pit crater but produced no lava.

The lava field is a moderately rough one with the lava flowing out in three main streams, leaving well defined ridges. The central ridge is piled high with the last gushings from the vent. Collapse due to lateral outflow has produced conspicuous slump forms along the margins of the flow.

Maungataketake

Maungataketake, Fig. 4, is separated from Otuataua by a segment of an extensive tuff mantle, the product of a number of local explosive vents, and the cone and its lava flows rest on the flank of a poorly defined tuff ring whose rim appears to pass directly under the cone. The sheet of tuff extends beyond the present coast and forms the cut platform for as far as it can be traced seaward. Along the south-east section of the coast the tuff is seen to rest on a surface of Pleistocene silts rising from below sea-level near the volcano to form the land surface farther to the south-east. The shore platform and the low cliffs of tuff are littered with trunks and limbs of Kauri trees, most of them prostrate but with a considerable number of stumps in position of growth. Many of the sticks are very large—up to 60 ft in length and 30 ft in girth—and much kauri gum has been recovered from the beach. Radiocarbon

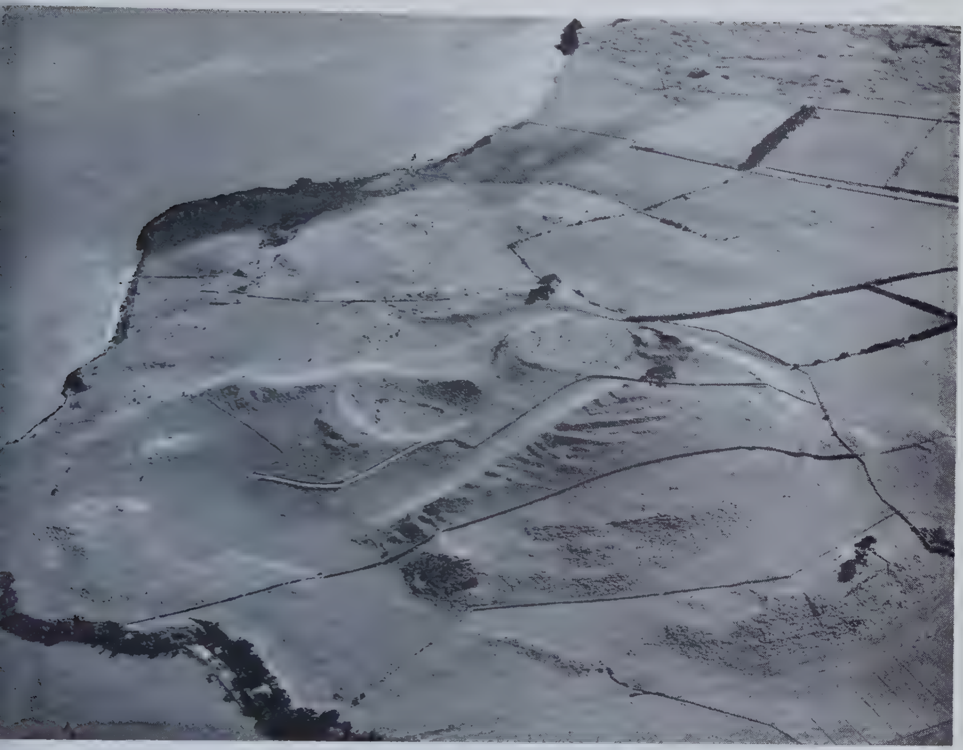

FIG. 4.—Maungataketake scoria cone and lava field, and beyond, a segment of tuff and the lavas of Otuataua.

Photo: Whites Aviation.

dating by Fergusson and Rafter (1959) fixes the age of a young sapling in position of growth as 2,900 ± 1,500 years before the present. It may be inferred that prior to the time of eruption a considerable kauri forest covered the area and that as a result of explosive eruptions the trees were felled either by the blast of the explosion or by the weight of tuff superincumbent upon them. Since the lavas of Maungataketake overlie the tuff it is apparent that cone building and lava effusion at this centre was a later event and it is likely that eruptions at Otuataua also occurred after the destruction of the forest since it, too, seems to be built on the same tuff mass. As has already been stated, eruptions at Waitomokia antedate those at Pukeiwi which, in turn, are older than those at Otuataua, but no data are yet available that will permit any certain time linkage of these events with those at Maungataketake. Nevertheless there is a suggestion (Fig. 4) that the lavas of Otuataua sit on ash which tends to cover those of Maungataketake and if this be verified, the former must be the younger feature. It may be accepted, however, that all these eruptions occurred during late glacial times when sea-levels were low and much of the area now occupied by Manukau Harbour was land surface. It would seem that eruptions took place near the margin of a board forested terrace cut in Pleistocene silts and standing at about 100 ft above the valley bottoms along which the main channels of the modern Manukau harbour are located.

At Maungataketake, as at the other local centres already described, no very large lava field was produced. Effusion seems to have been located about a single orifice with vigorous fire-fountaining shifting between various, closely spaced loci to build up a steep cone to a height of 240 ft, with a number of small and rather shallow craters indicating the later points of fountaining activity. The later and main outpourings of lava took place from the western flanks near the base of the cone and rafted away most of the debris that fell on that side. This left the south-east rim standing in a high peak above a pair of twin summit craters. A third crater, on the south-west at a lower level was close to the chief area of effusion and from it much of the later lava flowed down in steep cascades to form short flows.

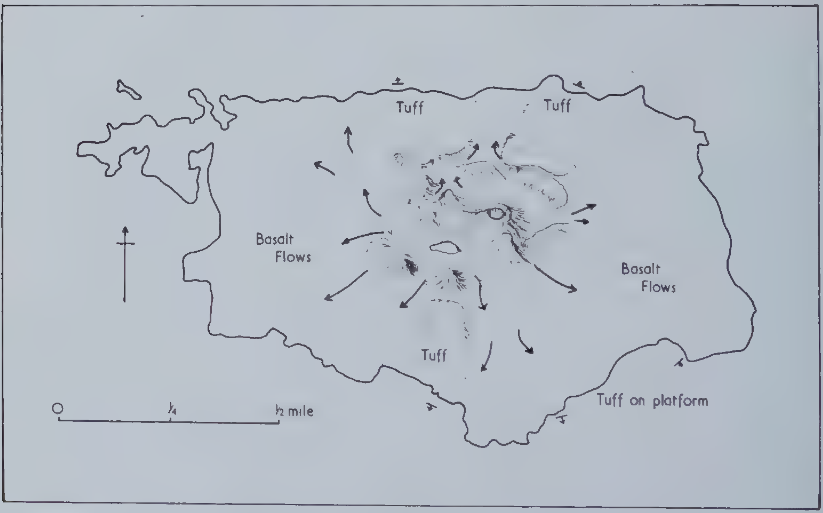

FIG. 5.—Sketch map of Puketutu Island showing main cones and craters.

Puketutu

The island of Puketutu (Fig. 5) has been formed by eruption from a group of many centres of activity. The earliest eruptions were explosive and built a tuff cone of considerable extent, a few isolated segments of which have survived subsequent disruption or burial and are preserved mainly in two remnants on the northern side of the island, and one on the southern. Elsewhere, particularly on the south and southeast, bedded tuffs are exposed in the shore platforms. They may be traced offshore for some distance, thus indicating not only the broad extent of the base on which the tuff cone rests, but also that these subaerial deposits stand on a surface at a level well below that of modern seas.

The greater part of the island is composed of basalt which has originated in a number of vents clustered in the centre of the area. The western flows were most abundant and have piled up lavas to a height of 60 ft above mean high water level. They extend seaward beyond the coast as submerged flows occasionally breaking the surface as shallow rocky reefs. The evidence suggests that these flows were formed before those on the eastern side of the island were poured out, for their surface carries much less ash. This, of course, could also be attributed to the prevailing direction of wind at the time the ash was erupted.

Minor explosive eruptions accompanied the outflow of lavas and associated fire-fountaining has built up a complex of scoria mounds. Frequent changes in the locus of activity has led to much mutual interference of constructural cones and has resulted in the production of a plexus of peaks, ridges, and poorly-defined craters, which provides little assistance to the unravelling of the eruptive history of the island.

Early in the effusive stage, explosive eruptions in the north of the island disrupted the tuff cone and fire-fountaining built up a scoria cone and poured lavas out to the east and north. A bore sunk for water supply in this area with collar height at approximately 60 ft above M.S.L., passed through broken basalt into scoria extending down well below sea-level and then into basalt to a depth of 50 ft below M.S.L. The site of eruption later moved to the south and west leaving intact only the northern flank of the earlier cone. In the eastern portion of the central mass evidence is preserved of a cone with a small entire crater, 30 ft deep, partly nested within the crater of a cone built earlier, whilst this, in turn, is surrounded by remnants of the still older cone mentioned above. A high peak to the south east of the summit crater and connected with it by a ridge stands at 210 ft and is craterless. Its origin is not clear but it is probably a remnant of some early cone.

Westward of the group of features just described much lava was produced, mainly from two breached craters which discharged flows through a small valley to the north and thence by a cascade to the lower levels. Round the vents scoria mounds were built to a height of 180 ft above M.S.L.

To the south of this integrated group of features and separated from it by a deep gulch at approximately 50 ft above M.S.L. are two craterless peaks. One, a scoria mound with a few basalt ribs, seems to have been part of a cone destroyed by outflow of lava from its base and through the gulch. The other may have a similar origin but it appears to be composed solely of blocks of dense basalt and may possibly be a block dome similar in nature to that figured by Williams (1932, p. 145). Domical structures are more common in acid fields than in basaltic ones but Williams (p. 136) notes that "if the temperature be sufficiently low, solidification fast, and the content of volatiles low, domes may develop among basalt lavas". Certainly much lava has been produced from adjacent areas and it may well be that this structure is such a block dome extruded during the dying stages of the vent.

The main interest in Puketutu lies in the complex relationship of its small topographic features, none built greatly in excess of 200 ft. Many of the larger volcanic piles whose outward symmetry suggests a much simpler history may in fact have had an equally complicated history, for as a volcanic edifice grows the evidence of previous events is easily destroyed or buried under the products of later ones. Apparent simplicity in final forms cannot be regarded as indicating a lack of complexity in the history of a centre.

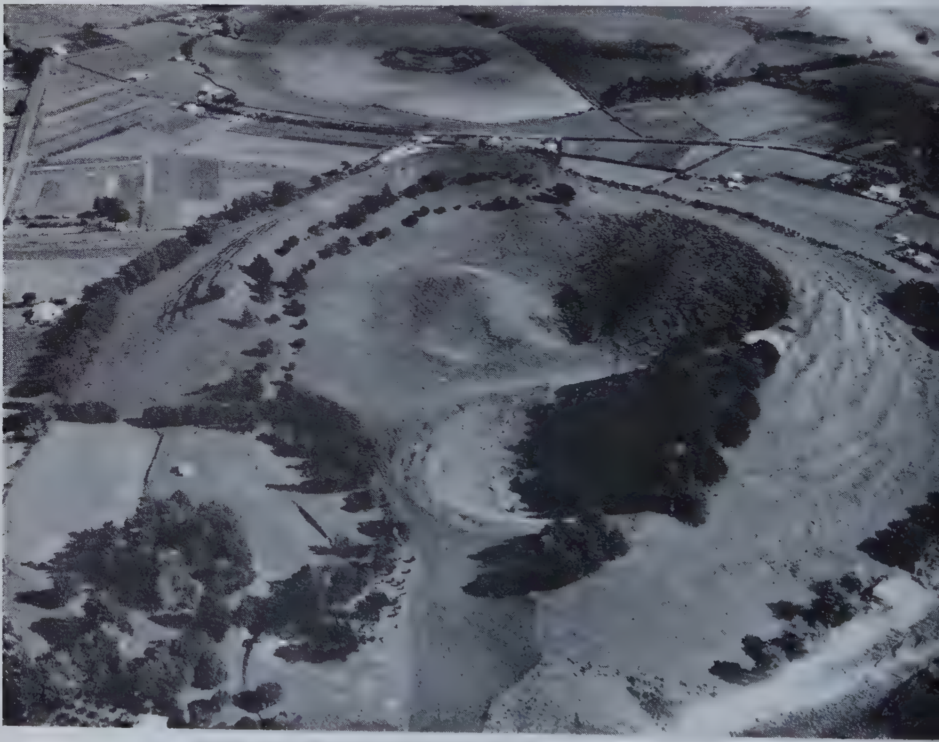

FIG. 6.—Mangere Mountain from N.N.E. At top Mangere Lagoon. Note alignment of main crater, tholoid and later crater in foreground. Explosion pits in main crater are clearly shown, as is also the offset in the crater rim.

Photo: Whites Aviation.

Mangere

At Mangere, Fig. 6, the volcanic landforms are also far from simple and present a picture of superimposed cones and interfering craters that indicate frequent recrudescence of activity from fresh vents in the system. At best, the study of the external form of the final structure can give only a very incomplete history of the later events at such a centre. Mangere mountain is 350 ft high, stands on a broad base, and is truncated by a particularly large crateral system. The south eastern and western parts of the rim are offset slightly in a saddle and the western rim is built to a much greater height. This relationship suggests that the centre of activity shifted to the north-west during the building of the main mass of the cone. The main crater is characterized by the presence of a tholoid-like cone surrounded by a number of crateral pits from which vigorous fire-fountaining hurled numerous large bombs that now litter the walls and floor of the very broad compound crater. A particularly vigorous vent in the north-west of the crater was no doubt partly responsible for the upbuilding of the high part of the rim adjacent to it. A late event in the summit history was the opening of a major vent in the northern part of the rim of the main crater. A considerable portion of the rim was blown away and the cone built about the new vent was built out to encroach into the main crater. Activity at this vent produced a very deep, steep-walled crater.

Mangere Lagoon, situated to the north-west at the foot of the mountain, is a large explosion crater with a low tuff ring breached to the sea on one side and now occupied by tidal mud-flat; it is to become a sludge lagoon for the sewerage plant now being established. In the centre of the lagoon is the summit of a small scoria cone with a shallow crater. From the manner in which the scoria slopes of Mangere mountain appear to rise from the tuffs it would seem probable that the phreatic eruptions that formed the lagoon took place before the fire-fountaining and effusive activity that built the main scoria pile.

On the north-north-east side of the mountain there was formerly a low cone that has since been almost completely removed in quarrying. This, too, was an older feature than the main cone and seems to have been partly wrecked before the latter was built as its flank toward the mountain was scarred by an explosion crater, now filled in to some extent with scoria from the main eruptions. An irregular mass of agglutinate in the quarry floor marks the site of the throat of this lesser cone. The lower part of the mound is composed to a large measure by massive blocks blasted from the cover rock when the vent was opened. Some of these blocks are of dense chilled lava whilst others are of sedimentary origin, mostly baked to a pink brick; a few have been completely fused to slag. These fused and indurated sediments, apparently representative of the upper sediments that enclosed the rising magma before the vent was opened, would seem for the most part to have been post-Waitemata in age since they include many acid tuffaceous grits and occasional baked lumps of shell-bed material, derived from the Pliocene beds of the area. The indications are that few, if any, have come from depths greater than between 100 ft and 200 ft below the surface. At higher levels in the cone scoriaceous and slaggy basalt and bomb fragments predominate, indicating that the explosive phase gave place to some fire-fountaining, and the uppermost layers are composed almost wholly of small scoriae and lapilli ejected as activity waned.

Lava has escaped at many points in the system. A major outflow, marked by a breached crater at a high level on the eastern flank of the main complex, produced a flow that covered a considerable area. Its surface is marked by a number of small mounds; some of these, near the breach, are composed of jumbled blocks and scoreaceous basalt and appear to be material from the edges of the rim of the cone that has been rafted away on the surface of the flow. Other mounds, farther from the mountain, are probably pressure ridges. The flow extends eastward as far as Tararata Creek, beyond which Hochstetter (1864) mapped a number of other volcanic mounds which he named Boulton's Hills. However, no volcanic materials other than a thin ash cover are to be found on the eastern side of the creek.

Other and more extensive flows emanating from other vents spread to the west and north, continuing for an appreciable distance beyond the present coast. Recently the Auckland Metropolitan Drainage Board has put down a chain of bores across the Manukau Harbour from Mangere to White Bluff on the Onehunga side. Bore records show that the lava extends for 900 yards from the Mangere shore to within 250 yards of the northern coast. A section, Fig. 7, constructed from the bore logs shows that, near this coast, the lava made contact with the Waitemata sediments which form a steeply rising slope along the southern border of the isthmus. The bores indicate that the lava flow, 15 ft to 20 ft thick and covered lightly with modern muds, rests upon poorly consolidated sands and muds. From one hole, a number of shells, all of the same species, were recovered at a depth of 34 ft below M.S.L. They were identified by Dr C. R. Laws, University of Auckland (pers. comm.) as *Zeacomantus* n.sp. Dr Laws notes that the species

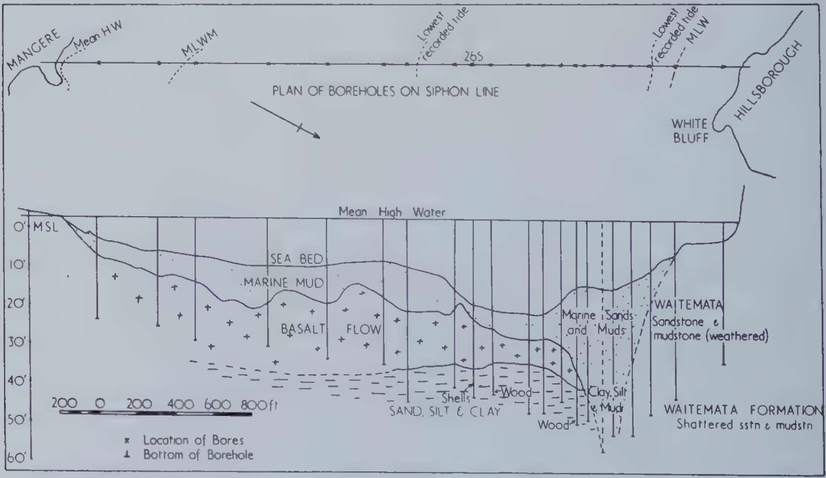

FIG. 7.—Section between Mangere and White Bluff (after A.M.D.B. drawing No. 1991) showing continuation of lava from Mangere across the floor of Manukau Harbour.

could have been derived from *Z. delicatus* (Laws) of the Otahuhu faunule but seem younger owing particularly to the weakening and acceleration of axials on the last two whorls. The development of spirals between the two peripheral cords separates the species from that of the Otahuhu faunule and also from the Recent *Z. lutulentus* (Kiener). The occurrence of the shells in poorly consolidated sands in this area suggests correlation with the fossiliferous beds already described near Mangere Lagoon and elsewhere in the district and until further information is available they are tentatively regarded as indicating that the sediments are part of the Otahuhu-Kaawa sequence.

Beds of this Kaawa Formation (Schofield, 1958) are unknown on the Auckland side of the Manukau Harbour and of Tamaki inlet of Waitemata Harbour. The steep slope on the Waitemata strata revealed by drilling apparently marks a shoreline of the basin in which the sediments accumulated. The driller's records describe the Waitemata sandstones and mudstones close to the face as shattered; the possibility therefore exists that the steep face is associated with the Manukau fault. However that may be, it is clear that in pre-volcanic times the smoothly undulating surface of the Pleistocene and Pliocene sediments forming the Manukau lowlands abutted the Waitemata sediments of the higher standing block of Auckland, and that along the line of contact a stream valley was incised. It was into this valley that the lavas from Mangere mountain flowed until arrested by the steep northern blank.

In the Auckland field as a whole, as has already been noted it is most difficult to determine any meaningful linear arrangement of centres because of the embarrassing number of lines that it is possible to draw passing through or very close to a number of centres. More significance can be attached to linear arrangement of vents associated with particular centres. In Fig. 1 such lines have been plotted for the Ihumatao, Waitomokia, and the Mangere volcanoes. These tie lines show clearly a marked distribution of vents about lines trending between north-northeast and north-by-east and suggest that the location of the volcanoes has been determined by a common intrusive body reaching the surface by means of fractures having these trends.

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BUCHIA PLICATA (ZITTEL) AND ITS ALLIES, WITH A DESCRIPTION OF A NEW SPECIES, *BUCHIA HOCHSTETTERI*

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(Received for publication, 15 July 1959)

Summary

Buchia plicata (Zittel, 1864) is illustrated by topotypes from Waikato South Head, New Zealand (Puaroan Stage, Lower Tithonian). *Buchia blanfordiana* (Stoliczka) from the Spiti Shales of Himalaya, judged by the lectotype and topotypes, is closely related to *B. plicata*. Specimens from the Edgar Range, Canning Basin, Western Australia, previously reported as *Buchia spitiensis* and *B. spitiensis extensa*, are illustrated and re-identified as *Buchia* aff. *blanfordiana* (Stoliczka).

Judged by the types and other specimens from Spiti, *Buchia spitiensis* forma typica (Holdhaus) and *B. spitiensis* forma *extensa* (Holdhaus) are, as Holdhaus maintained, merely variants in a single population. New Zealand specimens formerly classed in *Buchia extensa* are distinguished as a related new species, *Buchia hochstetteri*, characteristic of a zone in the Puaroan underlying the type horizon of *B. plicata*.

Lectotypes are chosen for *Buchia plicata, B. blanfordiana,* and *B. spitiensis*.

INTRODUCTION

One of the notable results of Hochstetter's geological exploration of Auckland Province in 1859 was the discovery of beds containing ammonites and belemnites which enabled him "to supply the first irrefutable evidence that Mesozoic formations were, in fact, not absent in the Australian realm, as had been long thought" (1859; 1864, p. 27). The first discovery was made on a ten-day excursion from Auckland by way of Manukau Harbour and Waiuku to the mouth of the Waikato River, in the latter half of January 1860. "Leaving the old mission station on the left bank of the Waikato near its mouth and crossing the sand dunes to the sea shore, one passes on the left the steep rocks, washed by the high tide, which form the Waikato South Head. The first projection consists of yellowish calcareous sandstone . . . I take these beds to be Tertiary. A broad fault zone . . . cuts off the Tertiary beds . . . Butting right against this fault comes a very thick complex of well-bedded marl and sandstone . . . It was here that I found the first belemnites, *Belemnites aucklandicus* Hauer, and also *Aucella plicata* Zittel, *Placunopsis striatula* Zittel, and small indeterminable bivalves" (précis from Hochstetter, 1864, pl. 28).

Zittel's description of *Aucella plicata,* with three illustrations of a single specimen, appeared in his article on fossil molluscs and echinoderms in the *Paläontologie von Neu-Seeland,* which was issued in

December, 1864 (Haast, 1884, p. 205). The genus *Buchia,* long known as *Aucella,* was known at that time chiefly from the Upper Jurassic and Lower Cretaceous of northern Europe, but was shortly afterwards found in India, America, and the Arctic. Zittel's species was the first to be recognized from the Southern Hemisphere, and, like many early names, *Aucella plicata* was misapplied, both in New Zealand (e.g., by Hector, 1870, pp. 192, 194; Boehm, 1911) and overseas (e.g., by Lahusen, 1888). Several factors contributed to its misinterpretation. Zittel's figure 4a was badly orientated, as he emphasized in a footnote (1864, p. 32). Hochstetter's locality, despite his accurate description, was not confidently located until B. H. Purser remapped the Waikato Heads district in 1952 (Purser, in press). The presence of other species of *Buchia* at Waikato Heads and elsewhere in south-west Auckland led to confusion. Purser's studies, noted by Marwick (1953, p. 97), have clarified the relationships of *Buchia plicata* in its type area and now allow the species to be illustrated from fine specimens, most of which are in the collections of the Department of Geology, University of Auckland.

Family BUCHIIDAE Cox, 1953.

Genus *Buchia* Rouillier, 1845

Type (by monotypy): *Avicula mosquensis* von Buch (Upper Jurassic, Russia).

In Opinion 492, the International Commission on Zoological Nomenclature (1957) placed the genus name *Buchia* Rouillier 1845 on the Official List of Generic Names in Zoology with the species cited above as type and placed the generic name *Aucella* Keyserling 1846 on the Official List of Rejected Names in Zoology.

Buchia plicata (Zittel). Figs 1–8.

1864 *Aucella plicata* Zittel. Novara-Exped. Geol. Theil. 1 (2): 32, Pl. 8, fig. 4a, b, c.

1911 *Aucella plicata* Zittel; Boehm, Neues. Jb. Min. Geol. Paläont. 1: 11–13 (not Pl. 2, f. 1–4).

1923 *Aucella spitiensis* cf. "forma typica"; Trechmann, Quart. J. geol. Soc. 79 (3): 267, Pl. 14, f. 7.

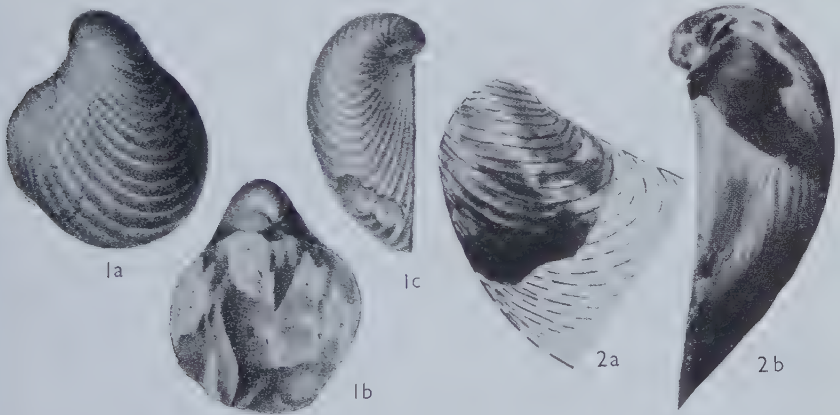
1923 *Aucella blanfordiana* Stoliczka; Trechmann, op. cit.: 268.

1924 *Aucella plicata* (Zittel); Marwick, Trans. N..Z Inst. 56: 304–5, Pl. 71, f. 7–9.

1936 *Aucella plicata* Zittel; Wandel, Neues. Jb. Min. Geol. Paläont. Beil.-Bd. 75 (B): 460, Pl. 15, f. 7a, b.

1953 *Buchia plicata* (Zittel); Marwick, N.Z. geol. Surv. paleont. Bull. 21: 96, Pl. 15, f. 16, 23.

According to Boehm (1911, p. 12), Zittel had 7 specimens in the *Novara* collections, but he figured only one, which is here designated lectotype (Fig. 1, a–c). As Zittel recorded in a footnote (1864, p. 32), the specimen was badly orientated by his illustrator, and this, coupled with Boehm's excessive caution and policy of lumping, led him to illustrate Kawhia specimens of quite a different species as *A. plicata.* Boehm's interpretation (based on comparisons of his Kawhia specimens with the *Novara* type) was followed by Trechmann (1923), who emphasized, however, that the Kawhia specimens are quite distinct from those collected at Waikato South Head by Marshall and Bartrum, for which he used names applied to Spiti Shale species. Krumbeck (1923) and Marwick (1924) independently named the Kawhia specimens as a distinct species, *A. malayamaorica* Krumbeck (= *A. boehmi* Marwick). Marwick also recognized *A. plicata* from Waiharakeke Bridge, Kawhia, and from Mangati Valley, Whaingaroa Survey District, and stated that specimens reported by Trechmann as *A. blanfordiana* are probably typical *A. plicata.* In 1936, Wandel re-illustrated the species with photographs of Zittel's figured specimen. Wandel's figures are repeated here (Fig. 2, a, b). They are the only available photographs of the lectotype, which is the only syntype remaining in the Naturhistorisches Museum, Vienna (Aqu.–Nr., 1865. XXVII 76).



Buchia plicata (Zittel).

FIG. 1, a, b, c.—Lectotype, × 1. After Zittel 1864, pl. 8, f. 4a, b, c.

FIG. 2, a, b.—Lectotype, × 1. After Wandel, 1936, pl. 15, f. 7a, b. Original of Zittel 1864, pl. 8, f. 4a, b. a.—view in normal position; b.—side view with completion of missing part.

Naturhist. Mus., Vienna.

The diagnostic characters of *Buchia plicata* are its large size (up to 85 mm); oblique elongation of the shell when fully grown (Fig. 4a); inflated left valve with arched, strongly incurved, somewhat twisted beak (Fig. 4 b); rather flat right valve, with anterior ear generally (but not always) small and inconspicuous (Figs 5, 8); and sculpture.

The direction of maximum elongation of the shell lies at an angle of 60° to 70° with the short hinge-line. The shell form bears the same relation to that of some other species of *Buchia* as the shell of *Gryphaea* does to normal *Ostrea,* and is perhaps adapted for a similar manner of life in fine-grained sediments. In consequence of the gryphaeoid habit, the ligament is attached to the dorsal edge of the right valve, on a nymph-like ridge that rises above the umbo (Fig. 5), and articulates with a downward facing ligamental depression on the posterior dorsal margin of the left valve. In young shells (Fig. 6), the left valve ligamental depression faces outwards, but in adults it faces ventrally below the overhang of the swollen twisted beak (Fig. 4, a, b). Well-preserved articulated specimens (Fig. 8) suggest that the ligament was exposed externally for about one-third of its length behind the beaks. The ear of the right valve fits in a shallow byssal sinuosity in front of the beak of the left valve, in front of which the anterior margin is commonly thickened (Figs 6, 8).

The shell is ornamented by rather regular concentric folds with a characteristic sinuosity anteriorly (Figs 3a, 4c). The points of ventral culmination of the folds representing the maximum length of the shell at each successive growth stage trace a gently curved axial line (Fig. 20). The outer shell surface bears spaced concentric imbricating lamellae, at first one to each fold, but crowded in later growth stages. Boehm noted radial striae on the lectotype, and they can be faintly seen in some of the specimens examined from the type area, but are not characteristic of the species.

Buchia plicata most closely resembles *B. blanfordiana* (Stoliczka) (see below). It is distinguished from *B. spitiensis* Holdhaus and from *B. hochstetteri* n.sp. by regular concentric sculpture (folds and lamellae) and from the latter by its less strongly twisted axial line. The Northern

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Buchia plicata (Zittel)

Plicata Zone, Puaroan Stage, Waikato Heads (Lower Tithonian).

Fig. 3, a, b.—Left valve. × 1. Lateral and posterior dorsal views. Waikato South Heads, coll. J. A. Bartrum. University of Auckland.

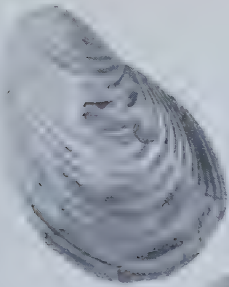
Fig. 4, a, b, c.—Complete shell, × 1. Right, left, and posterior-dorsal aspects. Huriwai River, 1 ft band in high cliff (Grid. Ref. 272910). University of Auckland, coll. B. H. Purser, 1952 (N 51/650).

Fig. 5.—Left valve, × 2, showing ligamental depression and byssal sinus. Huriwai River. University of Auckland, coll. B. H. Purser, 1952 (N 51/650).

Fig. 7, a, b.—Complete shell, × 1, right and left aspect. Huriwai River. University of Auckland, coll. B. H. Purser (N 51/650).

Fig. 8.—Complete shell, × 2, showing ligament and ear. Maretai Valley (Grid. Ref. 259934). N..Z Geological Survey, TM 2177, coll. B. H. Purser (N 51/642).

—*R. C. Brazier, del.*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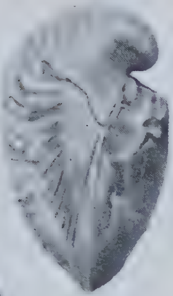
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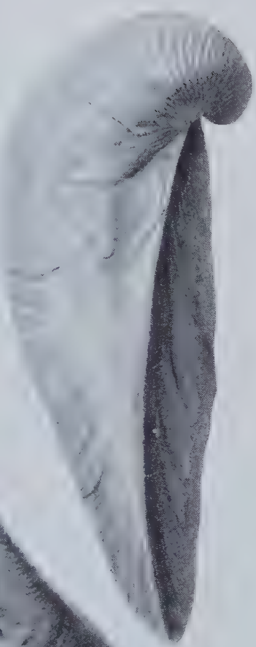
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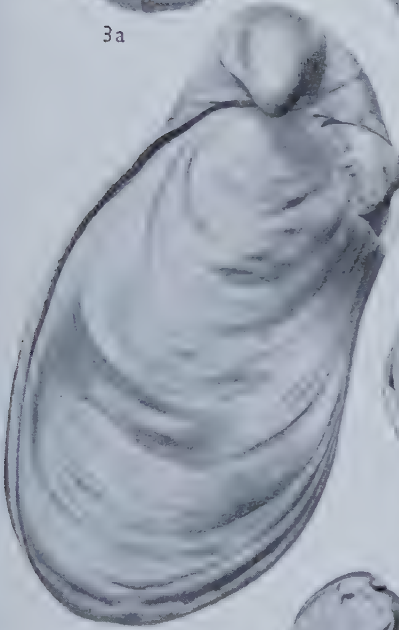
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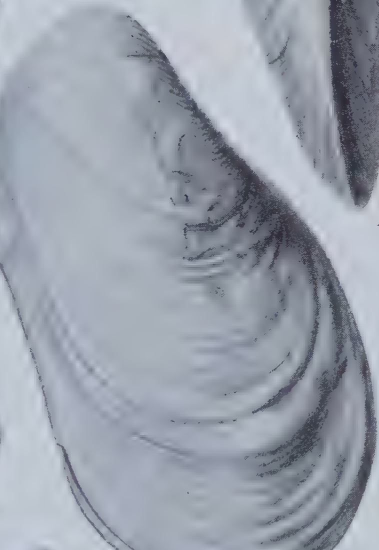
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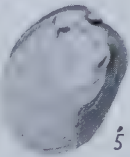
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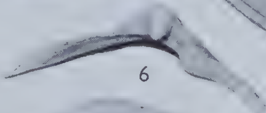
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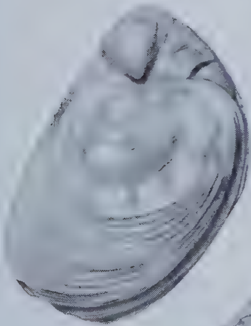
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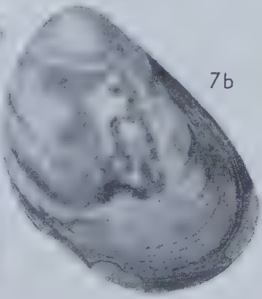
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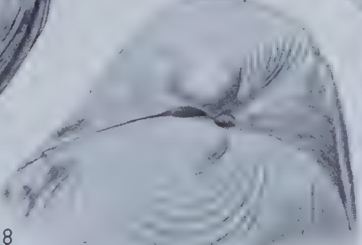
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Hemisphere species most like *B. plicata* appears to be *B. rugosa* (= *Aucella pallasi* var. *plicata* Lahusen 1888 = *Aucella sokolowi* Boehm 1911), distinguished by its small size and persistent radial sculpture (cf. Fleming, 1958, p. 382). Sokolov (1908, p. 24) united *B. plicata* with *B. crassicollis* Keyserling, a Neocomian species of the Northern Hemisphere which differs from *B. plicata* in its broader shell, more inflated right valve, and irregular growth, generally leading to a stepped profile.

LOCALITIES: For localities in Waikato Heads district, see Purser (in press). Figured specimens are from Waikato Heads (J. A. Bartrum), Huriwai River, and Maretai Stream; Coleman's Quarry, in conglomerate, Mangati Valley, Whaingaroa Survey District (GS 3851 coll. J. Henderson, 1920; 5255, re-collection by D. Kear and J. C. Schofield, 1950); other collections from this horizon, farther to the south-east, have been made by Mr R. A. Player (Auck. Univ. M.Sc. Thesis, 1958).

(?) Waiharakeke Conglomerate, Waiharakeke Bridge, Kawhia (Marwick, 1924, p. 304; 1953, p. 29), and near Oue Trigonometrical Station (GS 6488).

HORIZON: Mr B. L. Purser found that *B. plicata* defines a zone in the uppermost marine beds of Waikato Heads District, below the Huriwai plant beds and above a zone characterized by *B. "extensa"* (= *B. hochstetteri* n.sp.). Marwick (1953, p. 29) classed these beds in the Upper Ohauan Stage, but Purser maintained that they are Puaroan, a conclusion substantiated by Player (M.Sc. Thesis) and by Fleming and Kear (in press). Purser recorded the Lower Tithonian ammonites *Aulacosphinctoides brownei* (Marshall, 1909) and *Uhligites motutaraensis* (Boehm, 1911) from the *Buchia plicata* zone of Waikato Heads.

Neither record from the Waiharakeke Conglomerate is satisfactory. The specimens recorded by Marwick cannot be found and that from GS 6488 is a fragment, not entirely typical. This horizon is the base of the Puaroan stage (Fleming and Kear, in press).

Buchia blanfordiana (Stoliczka). Fig. 9–10.

1863 *Monotis concentricus* Blanford, J. Asiat. Soc. Beng., 1863 (2): 136, Pl. 4, f. 6–7 (not *Aucella concentrica* Keys.).

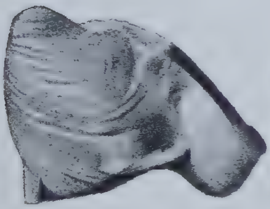
1866 *Aucella blanfordiana* Stoliczka, Mem. geol. Sun. Ind. 5: 88 (n. nov. for above).

1913 *Aucella blanfordiana* Stoliczka; Holdhaus, Palaeont. indica (XV) 4 (2): 397, Pl. 98, f. 1–9.

1913 *Aucella spitiensis superba* Holdhaus, Palaeont. indica (XV) 4 (2): 411, Pl. 97, f. 13 (?same specimen as figured by Pavlov, 1907, Pl. 1, f. 29).

Holdhaus (1913, p. 405) remarked that *Aucella plicata* Zittel, of which he had seen the types, is very closely allied to *A. blanfordiana*, from the Spiti Shales of the Himalayas, and Trechmann (1923, p. 268) identified two left valves and a right valve from Waikato South Head as "a form indistinguishable from *A. blanfordiana*", citing Holdhaus, Pl. 98, f. 3, 4. Marwick (1924, p. 305) noted that Waikato Heads specimens are topotypes of Zittel's species, which has priority over Stoliczka's, but could not determine whether they are identical.

Recently, casts of some of Holdhaus's figured specimens from the Spiti Shales, kept in the Indian Museum, Calcutta, have been supplied by the Geological Survey of India and have provided a basis for comparisons. The casts of *Buchia blanfordiana* represent the specimens portrayed in Holdhaus, Pl. 98, f. 3 (G.S.I. 10222, Jandu, Sherik R.), fig. 4 (G.S.I. 10223 "of unknown origin", Holdhaus, 1913, p. 414), fig. 7 (G.S.I. 10226, Sirkia, South Hundes), and fig. 9 (G.S.I. 10228, Niti Pass, North Kumaon).



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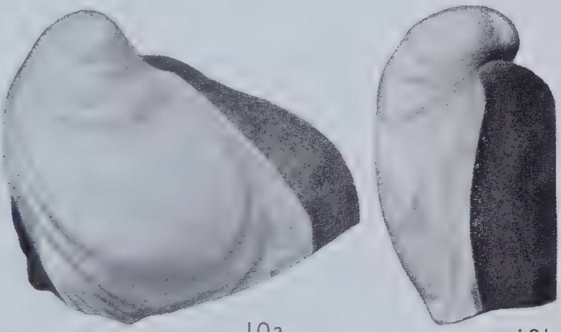

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10b

Buchia blanfordiana (Stoliczka).

FIG. 9.—Cast of lectotype (G.S.I. 10223), original of Blanford, 1863, pl. 4, f. 6, and of Holdhaus, 1913, pl. 98, f. 4. Spiti Shales, Spiti Valley, Himalaya. Coll. H. Gerard, Calcutta Museum.

FIG. 10, a, b.—Cast of left valve from Spiti Shales, Jandu, Sherik River (G.S.I. 10222), figured by Holdhaus, 1913, pl. 98, f. 3. Calcutta Museum.

—*R. C. Brazier, del.*

LECTOTYPE: The cast from the specimen "of unknown origin" (G.S.I. 10223) has been compared with Blanford's (1863) illustrations, and corresponds so precisely with his Pl. 4, f. 6, that it is confidently recognized as a syntype of *Monotis concentricus* Blanford and thus of *Aucella blanfordiana* Stoliczka; G.S.I. 10223 is here designated lectotype. The cast, here figured, lacks some of the detail of sculpture shown in both Blanford's and Holdhaus's illustrations, either because they were idealized, because the specimen has suffered during the intervening years, or probably (at least in part) because of imperfections of casting.

It is adequate, however, to justify Holdhaus's concept of the species as including his other figured specimens. Blanford's material consisted of Dr H. Gerrard's collection from the Spiti Valley, which is thus the type locality.

Pavlov (1907, p. 46, Pl. 1, fig. 29, a–c) published figures of "*Aucella blanfordi* Stoliczka" (sic) based on imprints taken in the Blanford collection in the British Museum (Natural History), but they cannot be matched among Blanford's figures, and the specimen seems to be the one figured as the holotype of *Buchia spitiensis superba* by Holdhaus (1913, Pl. 97, f. 13).

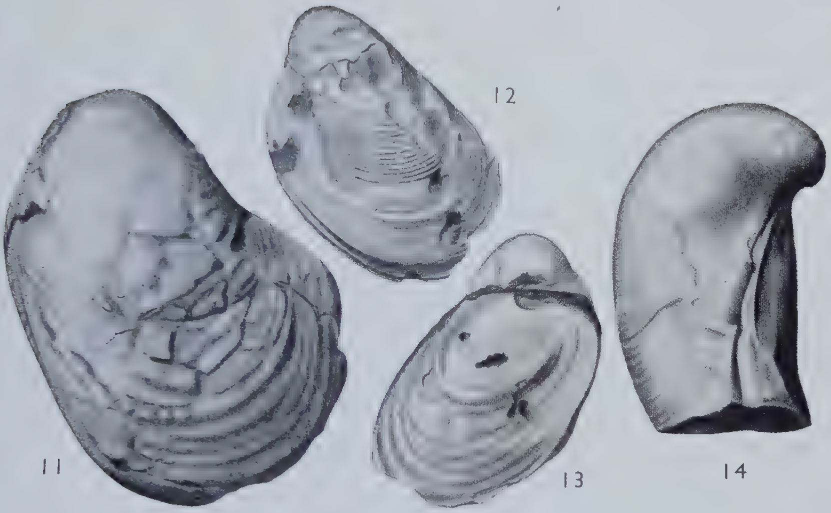
Holdhaus (1913, pp. 412–4) fully described the specimens available to him, in most of which, however, the shells had been entirely weathered away (p. 404). Judged by the four casts and by his description and figures, *Buchia blanfordiana* is very similar indeed to *B. plicata,* agreeing in general shape, inflation, and sculpture, including the lamellate ornament of the shell surface (Holdhaus, Pl. 98, fig. 9). The only differences noted may not be significant. The largest specimen of *blanfordiana* (G.S.I. 10222), estimated to have been 54 mm long, is considerably smaller than the largest *plicata* (85 mm). The shells are slightly less inflated, and the beaks less curved than in *B. plicata.* None of the Spiti specimens is as parallel-sided as the majority of *plicata*, and the single right valve (G.S.I. 10228, Holdhaus, fig. 9b) appears to have a larger ear and broader byssal notch than at least the majority of *plicata*. Although such differences may allow the New Zealand and Spiti populations to be differentiated when larger samples are compared, available data are inadequate for their distinction.

In the Upper Jurassic and Neocomian of the Boreal Province, a great number of *Buchia* species were distinguished by minor differences in shape or sculpture in individuals or small samples of fossil populations, for instance, by Pavlov (1907) and Sokolov (1902, 1908). Modern writers (e.g., Donovan, 1953) have suggested that these names need revising and synthesizing, and *B. blanfordiana* will probably prove conspecific with *B. plicata* when this is done.

Buchia aff. **blanfordiana** (Stoliczka). Figs 11–14.

1954 *Buchia* cf. *B. extensa* (Holdhaus); *B.* cf. *B. spitiensis* (Holdhaus); Brunnschweiler, J. geol. Soc. Aust. 1: 49.

From the Jarlemai Siltstone of the Edgar Range, Dampier Downs, north-west Australia, Brunnschweiler recorded abundant specimens of *Buchia* under the names *Buchia* cf. *extensa* and *Buchia* cf. *spitiensis* (Holdhaus). The Jarlemai Siltstone is attributed to the middle Tithonian and overlies beds with *Virgatosphinctes*, *Kossmatia*, *Inoceramus* cf. *everesti* (Oppel), etc., attributed to the Lower Tithonian-Kimeridgian.



Buchia aff. ***blanfordiana*** (Stoliczka).

Jarlemai Siltstone, Edgar Range, Dampier Downs, Western Australia. × 1.
FIG. 11.—Large left valve.
FIG. 12.—Left valve, showing sculpture.
FIG. 13.—Complete shell, showing ear.
FIG. 14.—Complete shell, postero-dorsal view.
From casts of specimens in Bureau of Mineral Resources, Canberra.
—*R. C. Brazier, del.*

Through the courtesy of Miss I. Crespin, Commonwealth Paleontologist, Bureau of Mineral Resources, Canberra, two of the Edgar Range collections have been examined by the writer. The two collections contain essentially similar specimens of *Buchia,* mostly lacking external shell layers, but otherwise fairly well preserved. Left valves, up to 75 mm in oblique length, resemble left valves of *B. plicata* in inflation and curvature, but are somewhat more like the large specimen of *B. blanfordiana* in detailed outline and beak contour (Fig. 14, cf. Fig. 10b). The smaller Edgar Range specimens bear regular spaced concentric folds, as do *B. plicata* and *B. blanfordiana,* and remnants of the outer shell layer show the characteristic lamellate sculpture of these species (Fig. 12). Older specimens, with the outer surface decorticated, show the same larger-scale growth depressions as large specimens of *plicata* and *blanfordiana* (Fig. 11, cf. Figs 4c, 10a). The more elongated specimens approach Fig. 4c in outline, but do not resemble the type of *B. spitiensis extensa* (Fig. 16a).

Right valves from Edgar Range (Fig. 13) have larger ears and byssal notches than the majority of *B. plicata,* and thus more closely resemble the single available right valve of *B. blanfordiana.*

As a result of these comparisons, the Edgar Range specimens are classed as *Buchia* aff. *blanfordiana* (Stoliczka), with the reservation that this species may eventually prove to be conspecific with *B. plicata* (Zittel). They are certainly closely related, and could be coeval.

Buchia spitiensis (Holdhaus). Figs 15, 16.

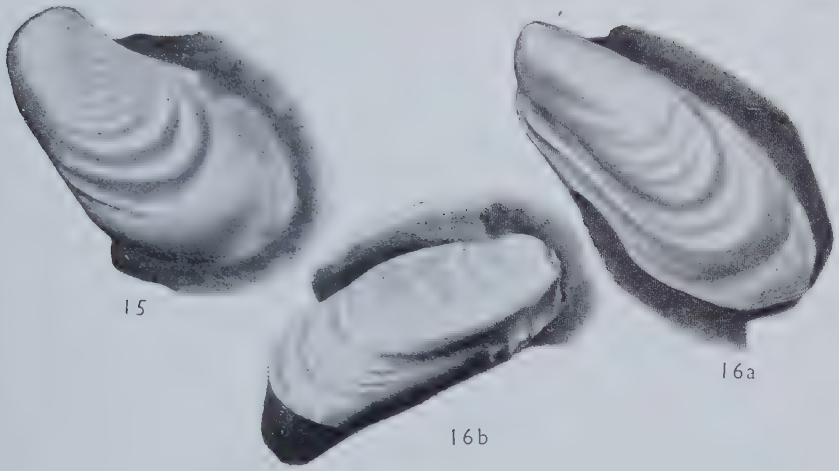
1913 *Aucella spitiensis* Holdhaus. Palaeont. indica (XV) 4 (2): 408–12, Pl. 97, f. 8–12 (including form. typ., form. *extensa*, and form. *grandis*).

LECTOTYPE (here chosen): G.S.I. 10216 (Holdhaus, fig. 10). Holotype of forma *extensa*: G.S.I. 10218 (Holdhaus, figs 12a–c).

Under this name, Holdhaus included a series of specimens characterized by their great obliquity and characteristic umbo shape, by broad concentric depressions on both valves, and perhaps by their ornament. He distinguished four forms (typica, *extensa*, *grandis*, and *superba*), which he thought "really synchronous variations of a single species". The writer has not seen specimens of *grandis* and *superba*, but casts of the holotype of *extensa* and of two syntypes of *spitiensis* "forma typica" (Holdhaus, Pl. 97, f. 10, 11) and the figures of *grandis* support Holdhaus's contention that these forms represent a single variable population, a contention strengthened by the records of specimens of *grandis*, *extensa*, and "forma typica" all from a single locality (Chidamu), and by the known variation in *Buchia* samples from a single locality and horizon in New Zealand. The holotype of *Buchia spitiensis superba* Holdhaus, on the other hand, is apparently the specimen figured by Salter (in Strachey, 1865) as *Monotis concentrica*, and by Pavlov (1907) as *Aucella blandfordi* Stol. (sic), and is more like *B. blanfordiana* than *B. spitiensis*, judged by the illustrations.

B. spitiensis is distinguished from the *B. plicata-blanfordiana* species-group by its very oblique narrower form, irregular growth leading to prominent growth sulci, by its less inflated and lower beaks, which appear broad and bluntly truncated in lateral view (Fig. 15), and by the absence of regular spaced concentric folds and, apparently, of spaced imbricate lamellae on the shell surface, though the outer surface seems to be lacking from syntypes. A related form from Misol, *Buchia subspitiensis* (Krumbeck, 1934), has also been recorded (as *Buchia* cf. *subspitiensis*) from subsurface formations at Broome, Western Australia (Teichert, 1940).

Holdhaus (1913, p. 405) speculated that *Buchia spitiensis* and *B. blanfordiana* (which occur in different localities) belong to separate stratigraphic zones in the Spiti Shales and inferred that the latter is the younger form, by analogy with the European succession from *B. bronni* Rouiller, 1848 (now known as *B. concentrica* (Sowerby,



Buchia spitiensis (Holdhaus)

FIG. 15.—Cast of Lectotype, × 1 (Holdhaus, 1913, pl. 17, f. 10). Spiti Shales, Jandu, Sherik River. Calcutta Museum (G.S.I. 10216).

FIG. 16, a, b.—Cast of Holotype of forma *extensa* Holdhaus, left and right valves, × 1 (Holdhaus, 1913, pl. 17, f. 12). Spiti Shales, Chidamu. Calcutta Museum (G.S.I. 10218).

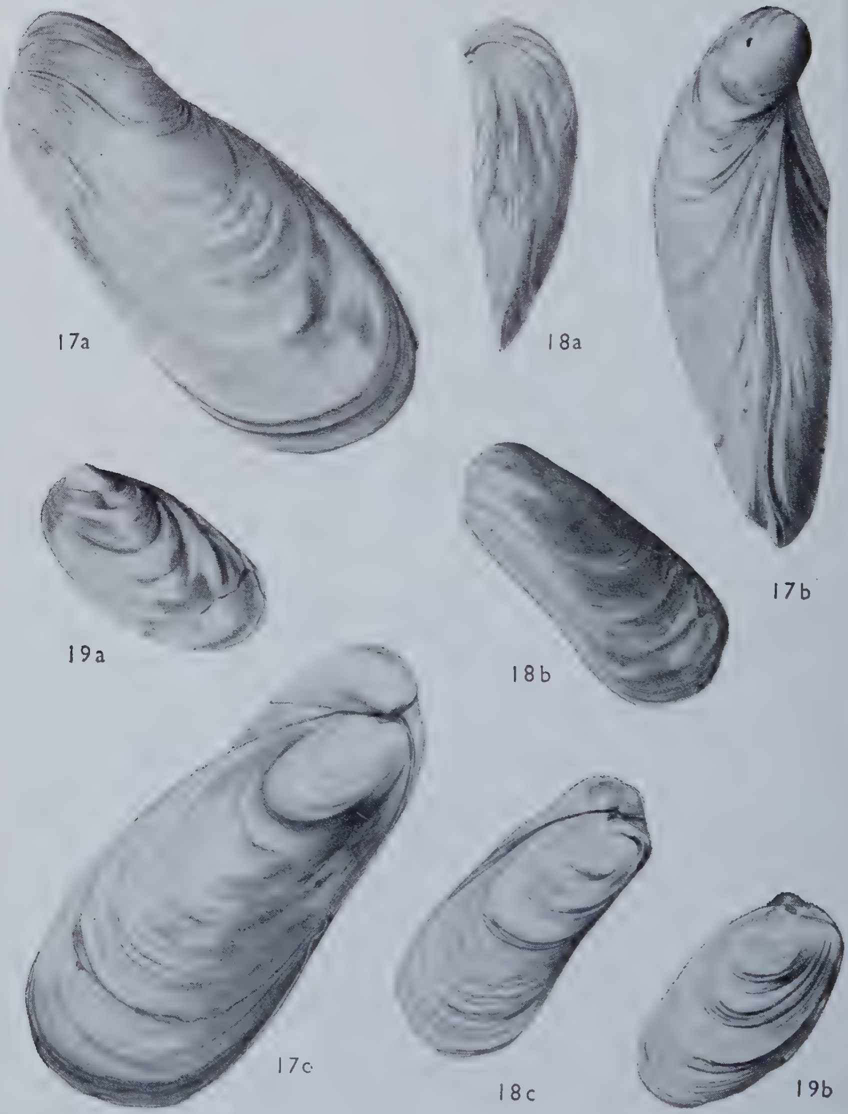
—R. C. Brazier, del.

1827), see Waterston, 1951) to *B. pallasi* Keyserling, 1846 (now known as *B. mosquensis* von Buch, 1844). Such a succession in the Spiti Shales, if confirmed, would agree with the succession from *B. hochstetteri* n.sp. (related to *B. spitiensis*) to *B. plicata* (Zittel) (related to *B. blanfordiana*) in the upper part of the Purroan Stage of New Zealand. In New Zealand, however, the time scale of the succession is much shorter than implied by the comparisons with Europe made by Holdhaus, since the two *Buchia* zones in New Zealand occupy but a small part of the zone of *Aulacosphinctoides brownei* (Marshall) in the Puaroan Stage, perhaps equivalent to part of the Chidamu Beds (Middle Spiti Shales), which contain similar *Aulacosphinctoides* (*A. hundesianus* (Uhlig), *A. chidamensis* (Uhlig), fide Spath, 1923), and *Uhligites* (cf. Arkell, 1956, pp. 407, 454).

Buchia hochstetteri Fleming n.sp. Figs 17–19.

1923 *Aucella spitiensis* cf. var. *extensa* Holdhaus; Trechmann, Quart. J. geol. Soc. 79: 267, Pl. 14, f. 5, 6.

1953 *Buchia extensa* (Holdhaus); Marwick, N.Z. geol. Surv. Paleont. Bull. 21: 96, Pl. 15, f. 21, 24.



Buchia hochstetteri n.sp.

Hochstetteri Zone, Puaroan Stage, Waikato Heads (Lower Tithonian).

Fig. 17, a-c.—Holotype, × 1. Left, postero-dorsal, and right valve aspects. Waikato Heads. N.Z. Geological Survey, TM 2174 (ex H. Suter Coll.).

Fig. 18, a–c.—Paratype, × 1. Antero-ventral, left and right valve aspects. Maretai Valley. N.Z. Geological Survey, TM 2175 (ex Auckland War Memorial Museum).

Fig. 19, a–b.—Paratype, × 1. Left and right valve aspects. Port Waikato-Kaawa Road (GS 5068). N..Z Geological Survey, TM 2176 (coll. C. A. Fleming).

—*R. C. Brazier, del.*

HOLOTYPE: N.Z. Geological Survey TM 2174, Waikato Heads, ex H. Suter Collection (probably Maretai Valley). Figured paratypes, TM 2175 (Maretai Valley) and TM 2176 (Kaawa Creek Road). Many other paratypes from Waikato Heads District.

HORIZON: Upper part of Puaroan Stage (Lower Tithonian), defining the zone of *Buchia hochstetteri* (Hochstetteri Zone), formerly "Extensa Zone", below the zone of *Buchia plicata*.

DIMENSIONS: Length (oblique) 71, width (oblique) 32, inflation (2 valves) 23 mm (holotype). Length (oblique) 43, inflation 14 mm (paratype, TM 2175).

A species of *Buchia* related to *B. spitiensis* Holdhaus, distinguished by its more constantly elongate form and by the spirally twisted growth-form of the left valve, which is thus strongly prosogyrous (Fig. 20).

Trechmann (1923) recognized the close affinity of his material with *B. spitiensis* var. *extensa*, but had few specimens. Marwick (1924, pp. 304–5) was impressed by the distortion of many Waikato Heads specimens and considered Trechmann's narrower forms to be probably varieties of *B. plicata*. Later (1953, p. 96), after B. L. Purser had discovered that the narrower form occurs consistently several hundred feet stratigraphically below *B. plicata* and is distinguished by lack of concentric lamellae and narrower form, Marwick admitted *B. extensa* to the New Zealand fauna. If *extensa* is merely an extreme form in the population of *B. spitiensis*, the New Zealand population, which is consistently elongated, is well distinguished taxonomically. If, however, the holotype of *extensa* is typical of a distinct population, its relationship with *hochstetteri* is closer, and perhaps best expressed subspecifically, but the twisted growth form apparently is characteristic of the majority of the population of *hochstetteri* in the Waikato Head-Aotea Harbour area. Just as *Buchia plicata* can be described as a *Buchia* with the growth-form of *Gryphaea*, so *B. hochstetteri* can be considered a *Buchia* with the growth-form of *Exogyra*.

One collection of *Buchia hochstetteri* in the Geological Survey is almost certainly wrongly localized. Collection GS 253 from "Pukeuri, Otago", collected by Traill in 1874, contains a single piece of indurated concretionary sitstone, with a weathered surface, approximately 8 × 5 × 4·5 cm in size, containing abundant separate left and right valves of typical *Buchia hochstetteri*. The rock is not metamorphic and the shells are undistorted. The specimen is not well rounded and its weathered (decalcified) surface sugests that it had not been transported as river gravel. Henry Suter examined the specimen and questioned the locality in an accompanying note, but stated that if the locality were correct he took it to be *Gryphaea tarda* Hutt., an identification published, with a query, in *N.Z. geol. Surv. paleont. Bull. 8*, p. 75. He also commented, however, that "the fossil has also some likeness to *Inoceramus* and *Aucella*". No other Upper Jurassic fossils have been reported from the watershed of Waitaki River (which passes Pukeuri), in which the pre-Cretaceous rocks are more metamorphosed than the specimen GS 253. GS 253 is quite similar to Waikato Heads specimens and is almost certainly wrongly attributed to Pukeuri.

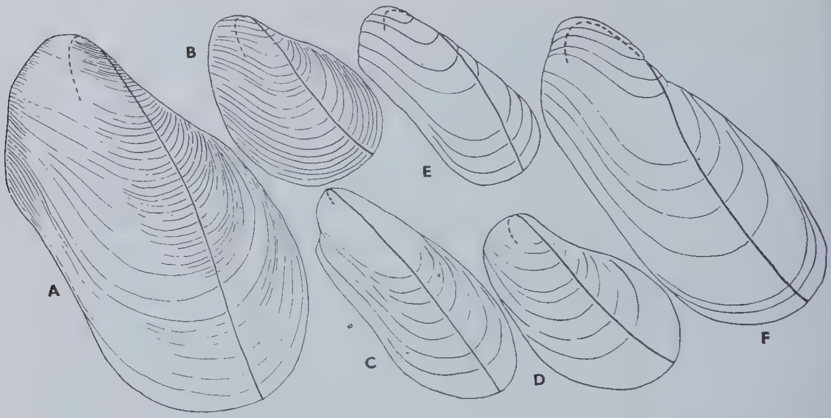


Fig. 20.—Diagram to show differences in growth form in three species of *Buchia*. In each figure an axial line joins the points of maximum elongation of the shell at successive growth stages. Its spiral course is diagnostic of *Buchia hochstetteri* n.sp.

A.B.—*Buchia plicata* (Zittel)
C.—*Buchia spitiensis* "form. *extensa*" (Holdhaus)
D.—*Buchia spitiensis* "form. typica" (Holdhaus)
E.F.—*Buchia hochstetteri* n.sp.

Acknowledgements

Several fine specimens of *Buchia plicata* from the University of Auckland collections were kindly lent for this study by Professor A. R. Lillie. Other specimens were received by exchange from Auckland War Memorial Museum through the good offices of Mr A. P. Mason. Acknowledgement is also made to Messrs B. L. Purser and R. A. Player for the use of unpublished stratigraphic data from Master of Science theses held at the University of Auckland.

The New Zealand Geological Survey is indebted to the Director, Geological Survey of India, and to the authorities of the Calcutta Museum for casts of type specimens of *Buchia* from the Spiti Shales.

The *Buchia* specimens reported by Brunnschweiler (1954) from the Jarlemai Siltstone of north-west Australia were borrowed from the Bureau of Mineral Resources, Canberra, and described by courtesy of Dr N. H. Fischer, Chief Geologist.

Thanks are expressed to Dr E. Flügel, Naturhistorisches Museum, Vienna, for information on the lectotype of *Buchia plicata* (Zittel).

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SODA-METASOMATISED ARGILLITES ASSOCIATED WITH THE NELSON ULTRAMAFIC BELT

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(Received for publication, 15 June 1959)

Summary

Petrographic, chemical, and X-ray study of indurated argillites associated with the Nelson ultramafic belt has indicated marked soda-metasomatism. The hardness of the argillites is due largely to albitisation, but additional toughness has been imparted, particularly in those specimens used by the Maoris for tool manufacture, by a felted crystallisation of minute tremolitic fibres. Hochstetter's hypothesis that the indurated argillites were included and altered by the ultramafites appears the most probable and is supported by comparison of the amphibolitisation of the argillites with nephritisation.

INTRODUCTION

To F. von Hochstetter's two-month stay in August-September 1859 we owe the first recognition of the size and importance of the ultramafic rocks in the Nelson Province. He wrote (1859, p. 96) "An immense serpentine dyke, of a thickness of several miles, stretches from the northern extremity of D'Urville's Island, across the French Pass, through the Croixelles, by Dun Mountain and Upper Wairoa, and is met again, on a continuation of the same straight line, on the Red Hills, near the Top-house, on the northern side of the Wairua Valley. This dyke can thus be traced from north-east to south-west for a distance of eighty miles." These ultramafic rocks which contain the type dunite discovered by Hochstetter (see Reed, 1959) are now known to be emplaced in upper Paleozoic rocks and to form the northern (Nelson) part of a discontinuous belt extending from D'Urville Island in the north to Mossburn in the south (Fig. 1).

Hochstetter further noted (1859, p. 96) "The strike of the serpentine dyke is perfectly parallel to that of the slates, but its eruptive origin is proved by the occurrence of a breccia of friction (Reibungs breccia) at the line of contact, and the fact of beds of slate enclosed in it being converted into hard and semi-vitrified cherts. The serpentine, in its turn, has been broken through by eruptive dykes of hypersthenite and gabbro." The enclosures of slate were described in greater detail (1864, p. 218): "On the south side of Dun Mountain can be seen a thick mass of slate compressed as it were between the serpentine of Dun Mountain and of Wooded Peak. The slate is grey, hard, cherty, and fractured into small pieces; but in all other characters resembles the Maitai slates. In the same way there projects on the summit of the saddle between Dun Mountain and Wooded Peak, a crag of grey rock resembling

N.Z. J. Geol. Geophys. 2 : 905-15.

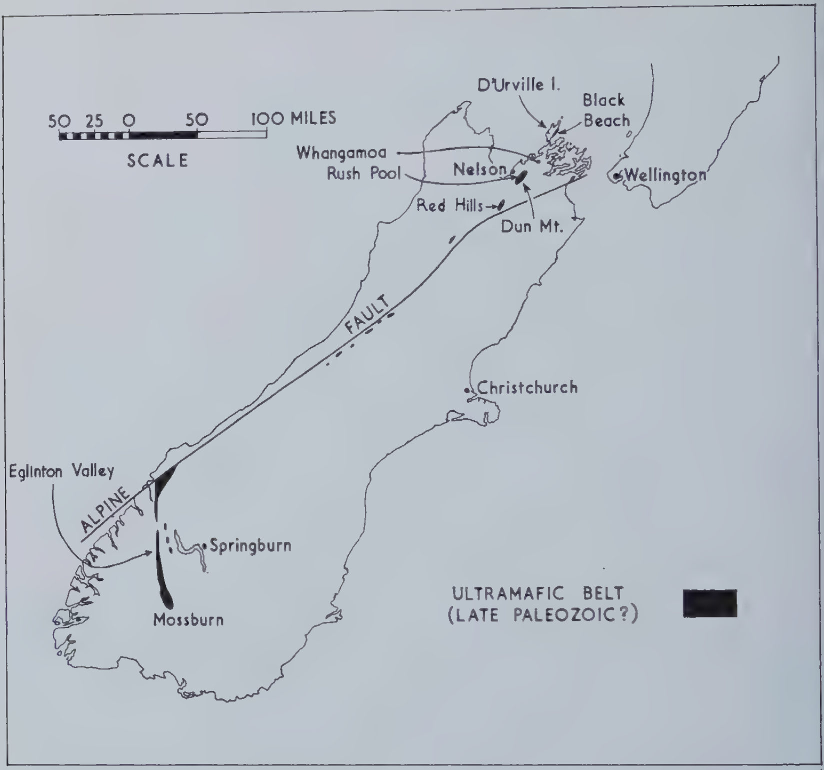

FIG. 1.—Locality map showing distribution of ultramafic belt.

siliceous schist which shows a regular rhomboidal jointing. The whitish grey blocks of this rock are clearly visible between the rusty yellow serpentinous rocks. I can interpret these rock fragments in no other way than as clay slate included in serpentine and altered." (Translation by C. A. Fleming.)

This paper is concerned with the indurated argillites (slates) which, as noted by Hochstetter, characteristically form projecting crags above the serpentinite and which generally weather to a whitish colour. In many cases the argillites form small or large lenses or "boulders" completely surrounded by serpentinite but in some places the discontinuity of the ultramafites and the irregularity of their boundaries makes it difficult to decide whether the argillites are large inclusions or whether they are margins to the ultramafites. In this respect it is possible that the original contacts may have been disturbed by later diapiric movements of serpentinite. The argillites are known particularly from the Nelson province but that they probably constitute a significant petrogenetic association throughout the main South Island ultramafic belt is shown by their known presence at the southern end of the belt, e.g. Eglinton Valley (Grindley, 1958).

Maori Rock Quarries

Unknown to Hochstetter, the indurated argillites associated with the ultramafites had long attracted the attention of the Maoris who sought and used the hardest and toughest argillites for tool manufacture. Their rock quarries are found in many parts of the Nelson Province and some of them have been described (Skinner, 1914; Thomson, 1918; Duff, 1946; Keyes, 1958). According to Duff (1946, p. 115) the Nelson-Marlborough area at the north end of the South Island has probably yielded more stone adzes to the square mile than any other part of New Zealand.

In 1938 the Dominion Laboratory analysed for the late Mr W. M. Jones a sample of argillite chips quarried by the Maoris from the contact with serpentinite at Black Beach, D'Urville Island (N.Z.M.S. 1, sheet reference approx. S11/252870). The sample was collected by Mr Jones when making magnetic observations that were later published (Jones, 1939), and he described the rock (p. 137B) as "argillite, which for 1 ft or so [next to the serpentinite contact] is indurated to a very hard rock of flinty texture, which was used by the Maoris for making implements". The purpose of the chemical analysis was clearly to determine the cause of the induration as is testified by the comments of the analyst Mr F. T. Seelye (unpublished Dom. Lab. report D 1282 of 3/6/38). "The C.I.P.W. norm is given below to show the highly feldspathic nature of the sample, and also, if the mode agrees with the norm, to indicate that the hardness and toughness of the rock are not likely to be due to silicification". The significance of these remarks was not realised, no further work was done on the problem, and the chemical analysis was not published.

Recently the unused parts of the analysed rocks have been located (P 17999*), and their study, together with that of samples from the Maori quarries at Whangamoa described by Duff (1946)—P 22921a and b, from the Rush Pool quarry described by Skinner (1914)—P 23314, and from the vicinity of Dun Mountain—P 11381, 22920, 22923, forms the basis of this paper.

Chemical Composition and X-ray Examination

Complete chemical analyses of two indurated argillites, one from D'Urville Island and one from Dun Mountain, are given in Table 1. The most significant feature is the very high soda content and low potash-to-soda ratio, in marked contrast to the potassic character and high potash-to-soda ratio in normal argillites (Shaw, 1956, p. 928; Reed, 1958, p. 36). The normative calculation indicates that the soda content represents 62% albite for the D'Urville Island sample and 47 to 48% for the Dun Mountain specimen.

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*Numbers refer to samples and thin sections in the petrological collections of the New Zealand Geological Survey.

Table 1.—Complete Chemical Analyses of Indurated Argillites.

	A	B*	C*
SiO_2	62·67	53·56	53·8
Al_2O_3	16·16	18·04	17·8
Fe_2O_3	0·54	1·47	1·1
FeO	4·15	4·23	4·5
MgO	1·70	4·08	4·2
CaO	3·09	6·81	6·8
Na_2O	7·03	5·05	5·3
K_2O	2·58	1·31	0·96
$H_2O +$	—	3·20	3·5
$H_2O +$ and carbonaceous matter	0·85	—	—
$H_2O -$	0·32	0·73	0·5
TiO_2	0·69	0·97	0·94
P_2O_5	n.d.	0·23	0·17
MnO	0·07	0·09	0·09
C	—	0·30	0·15
CO_2	n.d.	tr	0·05
	99·85	100·37	99·86

Molecular Norms†

	A	B*	C*
Q	2·0	−1·5	−1·8
or	15·5	8·0	6·5
ab	62·0	47·0	48·5
an	5·0	22·7	22·2
en	4·8	11·8	12·0
fs	5·2	4·4	5·4
wo	4·0	4·4	4·4
mt	0·5	1·5	1·2
il	1·0	1·4	1·2
ap	—	0·3	0·3
cc	—	—	0·2

*Through an oversight, different parts of the same sample were analysed separately by Messrs Seelye and Ritchie. Both analyses are published here as they afford a unique opportunity of comparing under normal working conditions the results of the classic volumetric methods of Mr Seelye with those of the more rapid methods developed by Mr Ritchie.

†Undersaturation is shown by deficiency in normative quartz rather than by undersaturated normative minerals (see Reed, 1957, appendix).

D'Urville Island

A. Indurated argillite (P 17999), serpentinite contact, Black Beach, D'Urville (N.Z.M.S.I. S11/252870)—see Jones, 1939, p. 237B. Unpublished Dom. Lab. analysis D 1282 of 3/6/38. Analyst F. T Seelye, Dominion Laboratory, D.S.I.R.

Dun Mountain

B. Indurated argillite (P 11381), "boss" surrounded by serpentinite, saddle between Wooded Peak and Dun Mountain (N.Z.M.S.I. S20/703207). Unpublished Dom. Lab. analysis Q1464/1 of 25/6/50. Analyst, F. T. Seelye, Dominion Laboratory, D.S.I.R.

C. Same as B but different part of sample. Unpublished Dom. Lab. analysis S919/1 of 9/7/54. Analyst, J. A. Ritchie, Dominion Laboratory, D.S.I.R.

Partial chemical analyses of four other argillite samples from the Whangamoa and Dun Mountain regions are presented in Table 2, and the results again indicate a very high soda content.

Table 2.—Partial Chemical Analyses of Indurated Argillites.

	Dun Mountain		Whangamoa	
	P 22923	P 22920	P 22921a	P 22921b
Na_2O	9·68	5·92	8·00	6·48
K_2O	1·17	2·7	1·94	3·24

Analyst: Miss M. G. Speer, Dominion Laboratory, D.S.I.R.

Dun Mountain

P 22923. Indurated argillite forming prominent "boss" surrounded by serpentinite, about 200 yards north of end of Dun Mountain Tramway, between Wooded Peak and Dun Mountain (N.Z.M.S. 1 S20/698210).

P 22920. Indurated argillite, in contact with sheared and partly serpentinized dunite, saddle south-west of Mt Dun (S20/700202).

Whangamoa

P 22921a. Indurated argillite, from worked face, Hebberds quarry, Whangamoa (N.Z.M.S. 1, S15/873433). See Duff, 1946.

P 22921b. Same as P 22921a, but coarser grained, discarded Maori chip from quarry.

X-ray examinations of the six samples analysed were carried out by Dr M. Fieldes, Soil Bureau, D.S.I.R., with the results given in Table 3. Dr Fieldes comments (pers. comm.) "X-ray powder diffraction patterns were obtained with FeK_α radiation on a Philips Geiger X-ray Spectrometer. Duplicate patterns corresponded closely and orientation was therefore reasonably random. Values of spacings read off from the diffraction patterns and approximate uncorrected relative intensities are shown in Table 3, together with figures for albite from an A.S.T.M. card for comparison. The lines at 3·33, 3·34, and 4·23 in samples P 22921a and b are probably due to quartz of which there is a trace in sample P 22921a and a few per cent. in sample P 22921b. Lines at 4·65, 4·31, 3·55, 3·50, and 2·73 are probably not due to albite. It was not possible to obtain any correlation between the alkali contents of the samples and the X-ray diffraction patterns. The results, together with the soda contents, confirm the presence of feldspar like albite in all six samples."

The absence of a 3·01 angstrom spacing suggests that the albite is the low temperature form (Tuttle and Bowen, 1950, p. 574).

TABLE 3.—Lattice Spacings (d) and Relative Intensities (I) for Indurated Argillites from D'Urville Island, Dun Mountain, and Whangamoa, and for Albite.

D'Urville Island		Dun Mountain						Whangamoa				Albite	
P 17999		P 11381		P 22923		P 22920		P 22921a		P 22921b		A.S.T.M. card 1/1791	
d(A°)	I	d(A°)	I	d(A°)	I	d(A°)	I	d(A°)	I	d(A°)	I	d(A°)	I
6·57	0·10	6·49	0·17	6·4	0·10	6·4	0·15	6·4	0·15	—	—	6·4	0·08
4·65	0·09	4·68	0·13	—	—	—	—	—	—	—	—	—	—
4·31	0·13	—	—	—	—	—	—	—	—	4·23	0·30	—	—
4·02	0·30	4·05	0·37	4·02	0·40	4·02	0·40	4·04	0·40	4·02	0·30	4·05	0·35
3·78	0·17	3·79	0·13	3·76	0·15	3·77	0·20	3·78	0·15	3·78	0·20	3·80	0·16
3·66	0·23	3·68	0·20	3·66	0·25	3·66	0·30	3·66	0·25	3·66	0·25	3·66	0·25
3·48	0·13	3·54	0·07	3·50	0·05	3·55	0·15	3·55	0·15	—	—	—	—
3·40	0·07	3·41	0·07	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	3·34	0·10	3·33	0·60	—	—
3·19	1·00	3·20	1·00	3·18	1·00	3·19	1·00	3·19	1·00	3·19	1·00	3·20	1·00
2·94	0·23	2·94	0·27	2·94	0·20	2·95	0·50	2·96	0·25	2·95	0·30	2·96	0·25
—	—	—	—	—	—	2·92	0·40	—	—	—	—	—	—
2·73	0·12	2·74	0·10	2·72	0·15	2·72	0·20	2·72	0·15	2·72	0·15	—	—
2·60	0·07	2·64	0·13	2·61	0·05	2·60	0·20	—	—	—	—	2·65	0·02
2·56	0·13	2·56	0·17	2·54	0·10	2·55	0·20	2·55	0·15	—	—	2·56	0·12
2·45	0·07	2·45	0·13	—	—	2·45	0·15	2·45	0·10	2·45	0·10	2·45	0·14

PETROGRAPHIC EXAMINATION

The samples are black or dark coloured, non-fissile, and possess a conchoidal fracture which is particularly well shown by the chips broken off by the Maoris. A thin white weathered surface is seen on most of the specimens.

The majority of the argillites are claystones (P 17999, 11381, 22920, 22921a) but grains of silt size are increasing in quantity in P 22923 and are abundant in P 22921b.

Cursory examination under the microscope suggests that the argillites have undergone little recrystallisation (Fig. 2) but closer study reveals the widespread presence of clear "interstitial" albite throughout the rocks (Fig. 3) with rare grains exceeding 0·05 mm in length. Measurement of the refractive indics of the albite in P 17999 gave:

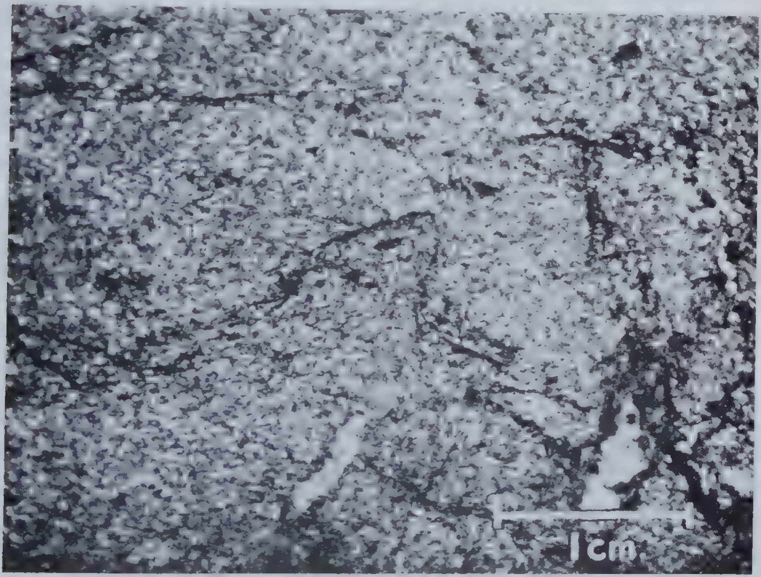

FIG. 2.—Photomicrograph of D'Urville Island argillite (P 17999) under low magnification giving impression of little re-crystallization. Shearing is indicated by discontinuity and contortions of bedding planes.

Photo: A. V. Weatherhead.

$$\alpha = 1 \cdot 523 \pm 0 \cdot 001$$
$$\gamma = 1 \cdot 538 \pm 0 \cdot 001$$

The "intersitial" crystalisation of the albite is clear evidence of the thorough impregnation of the rocks by soda-rich solutions.

Another feature found in all the samples, but particularly in those quarried by the Maoris, is a felted radiating network of minute fibres

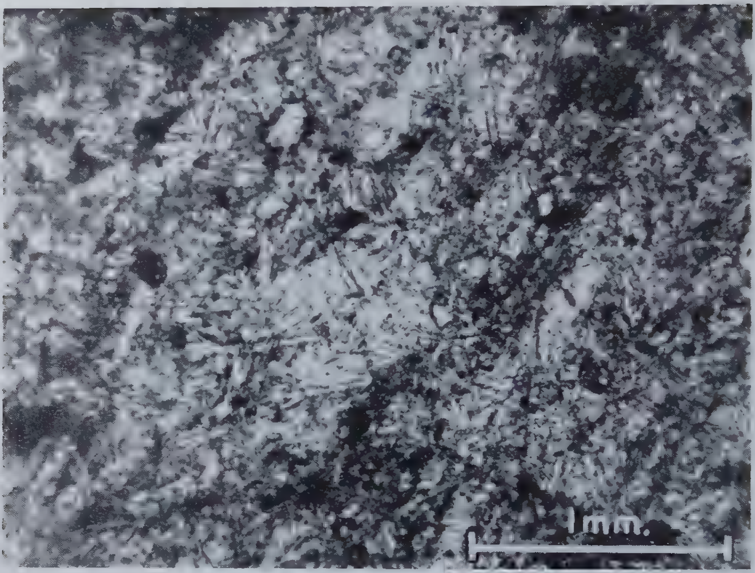

FIG. 3.—Photomicrograph of D'Urville Island sample (P 17999) showing clear albite distributed throughout rock. Some tremolite fibres are also shown.
Photo: A. V. Weatherhead.

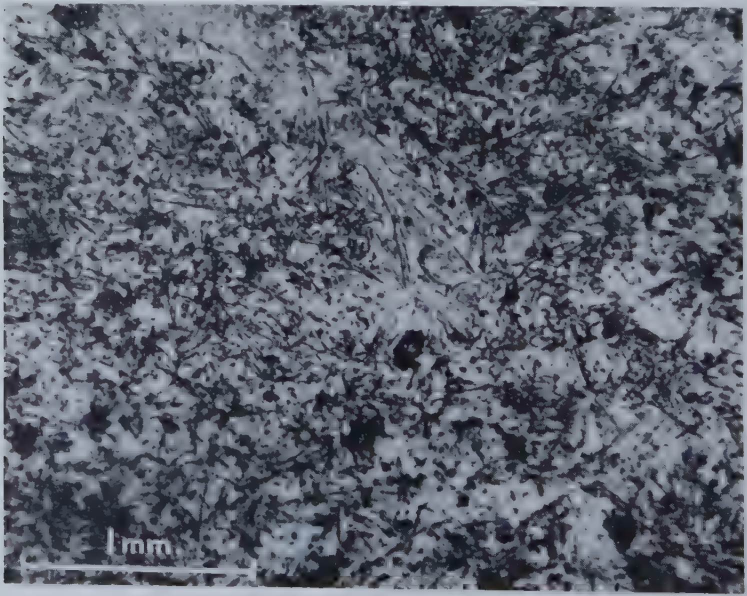

FIG. 4.—Photomicrograph of D'Urville Island sample (P 17999) showing felted radiating network of minute tremolitic fibres.
Photo: A. V. Weatherhead.

or acicular prisms whose average length is 0·05 mm and width 0·005 mm (Fig. 4). The small size renders identification difficult but the following properties suggest an amphibole of the tremolite group:

$$\alpha = 1{\cdot}610 \pm 0{\cdot}005$$
$$\gamma = 1{\cdot}630 \pm 0{\cdot}005$$
$$Z \vee C = 12\text{-}19^\circ$$
$$2V = \text{Large}$$

Support for this conclusion is provided by the X-ray examination for Dr Fieldes reports (pers. comm.) "X-ray data of three A.S.T.M. cards of tremolite show variations due possibly to differences in samples or difficulties in orientation. The cards are, however, similar in respect to a number of lines some of which coincide with diffraction lines of albite. It will be seen from Table 3 that X-ray lines common to the argillites that do not correspond to albite or quartz are close to 4·65, 3·5, 3·4, and 2·7 angstroms. Lines of reasonable intensity close to these four values do occur in the three A.S.T.M. cards and they are thus consistent with the presence of structures similar to tremolitic amphibole."

It is not known whether the tremolite is a soda type although comparison with Larsen's (1942, p. 49) data suggests that this is probable. The high FeO content in the analyses would also suggest that the amphibole is to some degree actinolitic. In some parts of the rock the fibres are a brownish tinge with straight extinction, and may be anthophyllite.

Veinlets and segregations of albite-tremolite (Fig. 5), quartz, and quartz-albite were noted and interstitial chlorite is another occasional secondary mineral. A stilpnomelane-like mineral accompanies a quartz veinlet in P 22921b. Marked shearing stress is indicated in most samples by discontinuity and distortions of the original bedding planes (Fig. 2).

DISCUSSION

Soda-metasomatism of the indurated argillites has been proved by chemical, X-ray, and petrographic study. Albitisation is a major factor in producing the hardness of the rocks but additional toughness has been imparted, particularly in those argillites selected by the Maoris for tool manufacture, by a felted crystallisation of tremolitic fibres. Similar crystallisation of tremolitic amphibole is found in New Zealand nephrites (Turner, 1935) and the amphibolitisation of the argillites is considered to be a similar process.

The only other example of soda-metasomatism associated with ultramafites in New Zealand appears to be adjacent to the small Springburn mass in Central Otago, for chemical analyses of mica schists adjacent to, and two yards distant from, the contact show a marked concentration of soda (Park, 1908, p. 80).

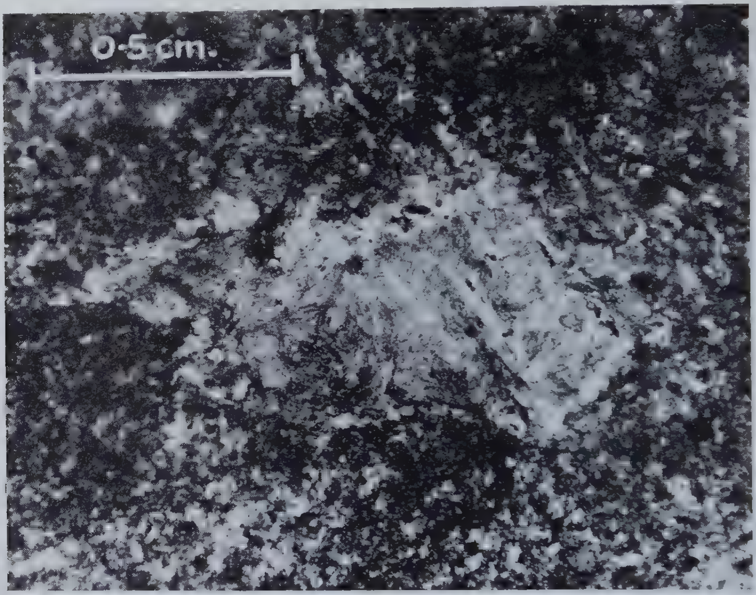

FIG. 5.—Photomicrograph of D'Urville Island argillite (P 17999) showing segregation of albite and tremolite.

Photo: A. V. Weatherhead.

Hochstetter's hypothesis that the indurated argillites were included and altered by the ultramafites appears the most probable and is supported by comparison of the amphibolitisation of the argillites with nephritisation. On the other hand, one of the argillites (P 22923) is known to be intercalated with metavolcanics (P 22925) but there is no evidence at present for considering the argillites, either partly or in whole, as adinoles at spilitic contacts. These questions of origin, however, must await additional field and laboratory study. The primary purpose of this paper is—

(i) to pay tribute to the accuracy of Hochstetter's descriptions;

(ii) to explain the hardness and toughness of the "Blackstone" so sought after by the Maoris;

(iii) to draw attention to the importance of the indurated argillites and the necessity to explain their occurrence and formation in any theory of ultramafite emplacement.

ACKNOWLEDGEMENTS

The writer is indebted to Dr M. Fieldes of the Soil Bureau, D.S.I.R., for X-ray data, and to Messrs F. T. Seelye and J. A. Ritchie and Miss M. G. Speer, Dominion Laboratory, D.S.I.R., for chemical analyses.

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CHEMICAL AND MODAL COMPOSITION OF DUNITE FROM DUN MOUNTAIN, NELSON

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(Received for publication, 15 June 1959)

Summary

A chemical and modal analysis is presented of the type dunite discovered by F. von Hochstetter on Dun Mountain, Nelson.

One of the most significant petrological observations made by F. von Hochstetter in New Zealand was his discovery of olivine rock outcropping in large masses on Dun Mountain, a conspicuous bare and rusty-brown coloured ("dun" coloured) mountain (Fig. 1) about six miles south-east of Nelson in the South Island of New Zealand. For this type of rock Hochstetter (1859, p. 96; 1863, p. 330; 1864a; 1864b, p. 218; 1867, p. 474) proposed the name "dunite", a term which has found a permanent place in petrological literature.

The most detailed account of the Dun Mountain area is given by Bell, Clarke, and Marshall (1911) but no chemical analyses of dunite were included. These authors overlooked the dunite analyses that were originally given in Hector and Skey (1866, p. 411) and later reprinted in an annual report of the Colonial Museum and Laboratory (1871, p. 17-8). Partial chemical analyses of six representative samples from Dun Mountain are included in a bulletin by Billinghurst and Nicholson (1956, p. 24) who also made a rough calculation of the quantity of dunite in sight.

No complete modern chemical analysis of Dun Mt. dunite is available, as is strikingly emphasized by Johannsen's (1938, p. 406) use of one of Hochstetter's original partial analyses. To rectify this position a complete chemical analysis by F. T. Seelye, Dominion Laboratory, is presented in Table 1, together with a point-counter modal analysis of the sample analysed.

Data on the minerals in Dun Mountain dunite are to be found in Ross, Foster, and Myers (1954), who give chemical and spectrographic analyses of the olivine, and chromite (chromian spinel), and a spectrographic analysis of the chromian diopside.

A study of the preferred orientation of olivine in Dun Mt. dunite has been made by Turner (1942).

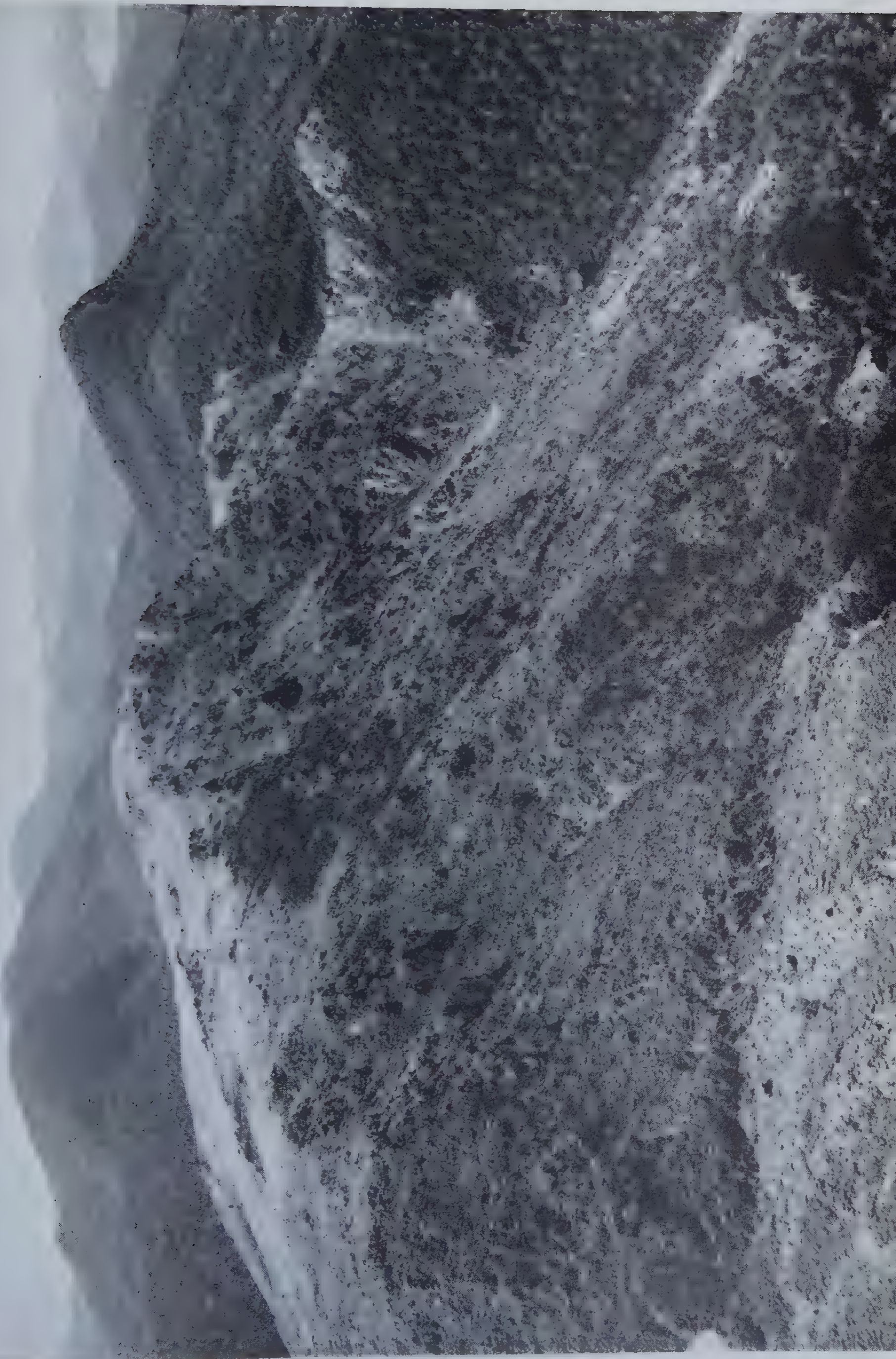

Fig. 1.—Aerial view of Dun Mountain looking at the south-eastern face and showing sparseness of vegetation on the dunite.

Photo C.A.A.—N.Z.G.S.

TABLE 1.—Chemical and Modal Analysis of Dunite from Dun Mountain.

SiO_2	39·53	
Al_2O_3	0·93	
Fe_2O_3	0·65	
FeO	7·62	
MgO	48·83	
CaO	tr	
Na_2O	tr	
K_2O	nt fd	
H_2O+	0·89	
H_2O-	0·16	
TiO_2	0·013	
MnO	0·12	
P_2O_5	nt fd	
CO_2	0·06	
S	tr	
NiO	0·32	
Cr_2O_3	1·01	
V_2O_3	nt fd	
BaO	nt fd	
ZrO_2	nt fd	
Cl	nt fd	
CoO	0·018	(equiv. to 140 p.p.m. of Co)
	100·15	

Olivine	97·5
Chromite (chromian spinel)	2·5
Chromian diopside	trace
Serpentine	trace
	100·0

Dunite (P 5728), from outcrop 60 chains SW of Dun Mt. trigonometrical station (NZMS 1, Sheet S20/708204). Unpublished Dominion Laboratory analysis G 6484 of 22/1/42. Analyst F. T. Seeyle, Dominion Laboratory.

The analyst reports: "Practically the whole of the nickel and also the cobalt is present in the portion of the sample soluble in diluted acids; on the other hand, the chromium appears to be present in the picotite mineral only, as not more than a trace of chromium could be extracted from the sample by means of hot (1:1) hydrochloric acid".

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A CENTURY OF GEOLOGICAL RESEARCH IN THE AUCKLAND PROVINCE

By A. R. Lillie, Department of Geology, University of Auckland

(Received for publication, 18 August 1959)

Summary

Following the initial discoveries of Hochstetter in 1859, geological research in the province was for a long time almost entirely the work of officers of the early Geological Survey.

This period lasted until the late "eighties", when Sir Algernon Thomas, first professor of natural science, encouraged a few of his students to take advanced degrees in geology and to publish the results of their researches on local geology. This research work of geologists at Auckland University College, at first intermittent, increased, particularly after the appointment of Professor Bartrum, and it now represents a substantial contribution to knowledge concerning the province. The information compiled at the University is most complete for the district surrounding the city of Auckland, where it has proved useful in engineering projects A short account is given of the careers of some pioneer survey geologists and university geologists.

A brief outline of the geology of the province omits reference to some of the more complex problems concerning North Auckland and the Central Volcanic region. Some emphasis is placed on the geology of Auckland city and its environs. The whole, accompanied by a simple correlation table, is intended to serve as an introduction to the student and visiting geologist. A reference list of some one hundred and forty papers, including unpublished theses, is included.

A Brief History

Among all the books on the geology of New Zealand, none leaves a more pleasing impression than the great volume of Ferdinand von Hochstetter (1864). The first glance evokes the past and a period when a scientific book was considered worthy of fine paper and figures of more than utilitarian quality: the prints and coloured lithographs delight the eyes of both the collector and the intelligent child; for the geologist, there is also the historical pleasure of walking with Hochstetter over new land for the first time, of marking the topography and geology on a base map that was "nicht viel mehr als ein weisses Stück Papier".

A closer reading inspires a considerable respect for the observant eye of the young Hochstetter, who early displayed an unusual maturity of thought in his interpretation of the geological structure. The ability to unite scattered and rapid observations into a coherent whole acceptable to the generality of later workers must always remain the test of really intelligent field work as distinct from merely routine description. As the materials collected by Hochstetter were described in the second volume (Hochstetter, Hornes, and Hauer, 1864) by eminent

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This paper was first read in 1952 on the occasion of the centennial of the Auckland Museum and at the invitation of the Auckland Institute. The paper has been revised to cover results of research until 1959.

N.Z. J. Geol. Geophys. 2 : 920-43.

specialists, including Zittel, the Reise der Novara includes a critical appreciation and comparison of fossils and rocks with those of regions outside New Zealand.

When we consider also that Hochstetter wrote German in a simple style, free from turgidity and pleasing to the English reader, whose dictionary is both a necessity and an irritation, we may indeed be grateful.

Other geologists examined the Auckland province and made scattered observations before Hochstetter, notably Dieffenbach (1843) and the pioneer surveyor, Heaphy (1854, 1860), and also naturalists of more considerable fame in brief visits, including Darwin, but to those interested in the Auckland region Hochstetter's remains the outstanding work, both for the detailed descriptions of the geology in the vicinity of the city and for the description of the country stretching from Auckland to Coromandel and as far south as Taupo and Mokau.

Hochstetter, a naturalist attached to the Austrian frigate *Novara*, commenced his survey of this region in 1859 at the special invitation of the Provincial Government (Hochstetter, 1859). Besides a journey in the North Auckland region, his travels included a visit to the brown coals of Drury and Hunua, whence he followed the Great South Road to Mangatawhiri and Ngaruawahia. He visited Waikato South Head, where he found the unconformable contact between Tertiary limestone and Jurassic strata, and found the now famous Mesozoic plant beds. Near Kawhia, he found ammonites and *Inoceramus,* and thence continued his travels through Mokau, Taupo, Tauranga, and then back to Waikato. This journey added a vast amount of new information, which was outlined in the maps compiled from his rough sketches by his compatriot, Petermann. Of these maps, the best known is that of Auckland itself (Hochstetter and Petermann, 1864; Hochstetter, 1864), which shows the Waitemata sandstones, the Manukau breccias, the Pleistocene silts, and the late volcanic cones and craters, the latter with great accuracy.

At the end of the "fifties", plans for geological research in New Zealand were well in advance of the arrangements for other scientific work: both the Colonial Museum and the Dominion Chemical Laboratory commenced much later and as adjuncts of the programme of geological research. In Otago and Canterbury, Hector and von Haast were appointed provincial geologists in 1861, and Crawford filled a similar post in the Wellington province in the following year. Few small countries have had men of such outstanding ability among their pioneer geologists.

Further research in the Auckland province for a long time later depended on the plans of Hector, for in 1865 he was appointed Director of the Geological Survey for the whole Colony. Dr (later Sir James) Hector graduated at Edinburgh with a medical degree, but his chief interests were always in the natural sciences. Two arduous years, in which he travelled more than a thousand miles, were spent in surveying the land between Saskatchewan and the Rocky Mountains. The conditions were often arctic in severity, and his work included all aspects of scientific observation besides surveying. His merit was realized in London, and in coming to New Zealand Hector rejected the offer of a more important post, involving political responsibility, for a very modest salary as a geologist. After a few years in the employ of Otago province, he became very soon the chief scientific adviser to the New Zealand Government and manager of the New Zealand Institute as well as director of the Survey.

The years of research in the Auckland province till 1900 were largely the work of a very few officers of the Survey—namely, Cox, Hector, Hutton, McKay, and Park. Of all New Zealand geologists, Alexander McKay is most appreciated today. Although he seems to have had few advantages of higher education, McKay had profited from solid Highland schooling, which he supplemented by his own reading. On first arriving in New Zealand, he started work as a gold-miner, but later was engaged by von Haast as a prospector and collector of moa bones; there seems little doubt that McKay must have learnt much from von Haast, but it is also evident that he had a remarkable flair for geological work. Within a short time, he had joined the staff of the Geological Survey, and from then until his retirement he contributed a stream of reports on the general structure of New Zealand more valuable, as a whole, than that of any other geologist, living or dead. McKay's faculty for drawing a synoptic diagram of field relations from a brief journey of one month or so was truly extraordinary, and, although his style of writing was indifferent, his observations were usually accurate, so that his recordings of facts can readily be distinguished from his more tentative interpretations.

James Park, who also came from Scotland, first commenced work on a sheep farm, but found his calling when he joined the Survey in 1878. After some years of field work, he was appointed to the Chair of Mining at the University of Otago and became an outstanding teacher through whose school passed several men important in the mining world. He was a prolific writer of text-books on practical geology and mining, one of which went into thirty-two editions. He died in 1947, at the age of 90.

The discoveries of those years of the early Survey are nearly all described in the Reports on Geological Explorations, which were discontinued after 1894. These early explorations covered roughly the whole country in rapid reconnaissance. The Survey, with a reduced staff, then published a few reports in the Mines Statements and scattered journals until it was reorganized in 1905 under the directorship of Bell (1905–11). On Bell's departure for Canada, Morgan (1911–27) succeeded him. Directors for later periods include Henderson (1928–46), Ongley (1947–52), Grange (1953–56), and Willett (1957). The policy of Bell and Morgan was in general to cover the country with more detailed mapping, which is still in progress. The results of this detailed mapping are published intermittently in the Bulletins of the

Geological Survey, which generally attempt to cover most aspects of the geology of a region. They include discussions of geomorphology, paleontology, petrography, and the local mineral resources, and are accompanied by coloured maps. Special Bulletins are devoted to paleontology.

Certain aspects of geological research have always depended on a considerable organization to compile the results for a whole country. This is particularly true of precise stratigraphy, on which much geological work depends, for the value of certain faunas as widespread and accurate age indicators can only be assessed empirically by judicious examination of thousands of collections gathered from a large area. The need for such organization is even more imperative in a country where workers in the universities have had few facilities and little time for research, so that the integration of several different lines of stratigraphic evidence has been very much a matter for specialists in the Survey, especially when the reconnaissance stage has been passed. The work of the early Survey was essentially structural, stratigraphical, and economic, with petrographical work subordinate. On the paleontological collections, Hutton, who was a man of extremely wide interests and learning, made valuable contributions, but was handicapped by the extent of his other duties, which included the posts of Curator of the Canterbury Museum and Professor of Biology at Canterbury. Suter and the brilliant Allan Thomson, as well as European specialists, contributed to the early Paleontological Bulletins of the Geological Survey and laid the foundations for intensive study of the Survey collections. Following Thomson's death, Dr J. Marwick, in 1920, was appointed paleontologist to the Survey and actively continues his research today. When Marwick was joined by the late Dr H. J. Finlay (appointed micropaleontologist in 1937), both workers commenced a close scrutiny of the field work and collections of preceding years in terms of biostratigraphic concepts that allowed very close subdivision of the Cretaceous and Tertiary into many stages. The resultant picture, of which only part has yet appeared in print, indicates a complex picture of intermittent earth movements, with consequent unconformities and overlaps formed throughout Cretaceous and Tertiary times. Of early ideas, those of Allan Thomson's paper on diastrophic provinces (Thomson, 1917) most nearly approximate to these present interpretations. The work done by a very few paleontologists has made a tremendous difference to the integration of field geology in New Zealand, and the work of Finlay and Marwick remains as one of the landmarks in New Zealand geology comparable to that of Hochstetter. Of recent years, this has been amplified by the scholarly work of Fleming, Hornibrook, and several able assistants.

The economic potentialities of any region always affect Survey policy, and in this respect the North Auckland Peninsula offered little reason for intensive examination by officers of the Survey: interest was largely transferred elsewhere, after preliminary survey of a few areas. Only three Survey Bulletins have as yet appeared on the North Auckland region. Bell and de Courcey Clarke, later Professor at Perth, Australia, wrote the Whangaroa Bulletin (1909) and Ferrar described the Whangarei (1925) and Dargaville-Rodney (1934) subdivisions. Details at Whangarei Heads have been described by Bartrum (1937a) and Allen (1951). Ferrar had been geologist on Scott's first (*Discovery*) expedition, and also carried out some of the pioneer survey work in connection with bush-sickness in the King Country. Ferrar's field work covered a large tract, but was completed before the introduction of micropaleontological zoning and, unfortunately, macrofossils are comparatively rare in most of the rocks. Now, of all fields in New Zealand, that of North Auckland is probably the most difficult, in the absence of many fossils, to map in terms of any coherent stratigraphic scheme. The most extensively exposed strata are those of Cretaceous and Tertiary formations, which contain numerous facies variations in rocks of the same age: exposures, often widely separated, show rocks much disturbed by slumping and altered by the deep weathering which prevails. In consequence, the field still awaits the comprehensive vision of some worker in the Survey who will map a very large part of the province with the constant collaboration of the specialists. Until this is done, a detailed comparison of findings of the early and later Surveys would be futile. Results of regional mapping are at present being prepared for publication by Mr R. F. Hay, of the Geological Survey.

South of Auckland, more progress has been made, and several bulletins and reports by Ferrar (1930), Henderson and Grange (1926), Marwick (1946), Henderson and Ongley (1923), Williamson (1932) have covered the Mesozoic strata which, with an aggregate thickness of 28,000 ft, range in age from Middle Triassic (Ladinian) to latest Jurassic or early Neocomian, and which can be precisely correlated with those of the Hokonui region of Southland (Marwick, 1953). The Tertiary strata still present problems of correlation, but they are on the whole much better exposed and more clearly described. With one possible and curious exception (mentioned later), the Cretaceous system appears to be absent south of Auckland city, and the earliest coals are of Eocene age.

The preliminary survey of the Rotorua-Taupo region was covered in a bulletin by Grange (1937), and the whole of the central Volcanic region is now being investigated by the volcanological section of the Survey under the leadership of Healy (1949). This region is too complex to permit discussion here, especially as much of the accumulated information is unpublished.

Mining activity in the Cape Colville Peninsula inspired survey parties to map the whole region in detail, and Morgan (1924) presented a general picture, questioned by some, of three main volcanic periods and of mineralization not later than the earlier part of the second period. The authors of the bulletins include Fraser and Adams, 1907; Fraser, 1911; Bell and Fraser, 1912; Henderson and Bartrum, 1913; Morgan, 1924. A petrographic volume by Sollas and McKay (1906) has also been published.

THE AUCKLAND SCHOOL OF GEOLOGISTS

On the whole, the research of university workers only became significant for the development of geology in New Zealand at the beginning of the century. Sir Algernon Thomas, first Professor of Natural Science (between 1886 and 1914) at Auckland University College, contributed valuable descriptions to some bulletins, and his original papers on geology included notes on the geology of the Taupo district (1888b, 1889) and a report on the eruption of Tarawera in 1886 (Thomas, 1888a), also described by Smith (1886), Hector (1886, 1887), and Hutton (1887). Although primarily a biologist, his influence as a teacher of geology was much wider than his published work would indicate, and he was consulted on many aspects of practical geology. In the early days of the College, however, few students proceeded to advanced classes in geology. When Bartrum (1885-1949) in 1914 was appointed lecturer at Auckland, a new phase of geological research began in the province, for, under his inspiration, his advanced students covered a large field, at first mostly near the city, but in later years spreading much farther. The contributions of university geologists to local knowledge now became important, and the accumulated knowledge of Bartrum and his pupils has added to the material welfare of the city to a degree well appreciated by local engineers but by few others.

Bartrum's interests were not narrow: he wrote on geomorphology (1926a, 1938, 1939b; Bartrum and Branch, 1936), stratigraphy, mineralogy, and petrography, but his chief interests lay in the latter field and in the phenomena of volcanology. He believed in precision and the objective statement, and, although he had his own speculations on more theoretical aspects of geology, he hesitated to commit them to paper; presumably he would have considered his own ideas to be "half-baked", for Bartrum was a modest man. His petrographic work, of high quality, is best exemplified by several papers on serpentinites, pillow lavas, and many volcanic rocks of the Auckland province, and by a particularly interesting summary (1925) of the igneous rocks of North Auckland. Most descriptions of the Auckland volcanic rocks are the work of Bartrum or of his students, but the contents of many of these petrological papers are too specialized for discussion here (1925, 1926b, 1928, 1930c, 1936, 1939a, 1944, 1948; Bartrum and Turner, 1928).

Many of Bartrum's students have become notable research workers, especitally in universities. Among those who shared his special interest in petrology are: Dr F. J. Turner, now professor in the University of California and a leading authority on metamorphism and petrology as well as the deformation of crystals under stress; Mr E. J. Searle and Dr R. N. Brothers, senior lecturers in the University of Auckland, who have worked on problems of petrology and geomorphology in the Auckland district; Dr R. H. Clark, professor of geology at Victoria University of Wellington; Dr M. H. Battey, now lecturer in petrology at the University of Durham; and Dr H. J. Harrington, lecturer in petrology at the University of New England, Australia. All these workers, besides contributing to petrology, have maintained their interests in other aspects of geology.

This wider interest in geology as a whole, fostered by Bartrum, is indicated by the paleontological research contributed by other pupils. Dr C. R. Laws, now Senior Lecturer at Auckland, has published many papers on the molluscan faunas of Auckland Tertiary rocks; Dr C. A. Fleming, Chief Paleontologist of the Geological Survey, has made considerable and scholarly contributions to paleontology and stratigraphy; Dr R. A. Brown, now professor at Canberra University College, has become an authority on bryozoans.

Bartrum's special interest in volcanology is shared by Mr J. Healy (1949), who is now volcanologist at Rotorua and actively connected with all the present schemes for tapping geothermal energy and also with investigation of dam sites.

After several years as a geologist with an oil company, C. W. Firth turned his energies to waterworks engineering for the city. He and A. D. Mead have handled complex problems requiring a very close study of geological as well as engineering factors. In this work, their thorough knowledge of the geology of the catchment areas (Mead, 1930; Firth, 1930) has been of great advantage.

E. J. Searle, in his own research work, has followed most closely the research interests of the late professor, and, like Bartrum's work, Searle's detailed knowledge of local geology has also proved to be of great use in several engineering projects. At present he is engaged in a complete study of the geomorphic and volcanic history of the Auckland isthmus to be eventually incorporated into a map and memoir on the geology of the region, planned as a joint project by the department of geology at the university.

Although Dr A. W. B. Powell, of the Auckland Museum, is primarily a marine biologist and oceanographer, his contributions to descriptions of Auckland fossil faunas should be mentioned here; the Conchology Club of the Museum has done much to stimulate an interest in paleontology. We can count him among our most distinguished graduates.

Mention should also be made of the work of Professor Marshall (1869–1950), who, besides describing the volcanic rocks of Auckland city, also wrote a paper on the Cretaceous ammonites of the Kaipara Harbour (1926).

Since the middle "forties", a considerable amount of regional mapping has been done by R. F. Hay, and bulletins now in preparation by him should clarify the confustd stratigraphy of the North Auckland province.

In the late "forties", a new development has been the establishment of a Geological Survey office, first at Ngaruawahia and then (1958) moved to Auckland. The return of the Survey to the Auckland province marks a new phase of research in which we, in the university, can expect to continue our friendly collaboration but on closer terms. It seems fitting at this point to emphasize the amount of valuable research that has been done over many years in the Auckland region, largely by workers from the University of Auckland, and one may insist again that this work in the area surrounding the city has also yielded considerable economic gains. Furthermore, nearly all this research has been done at the private expense of the staff and the students concerned; the amount received from research grants, entirely from the meagre research funds, over several years between 1918 and 1959 probably does not exceed in all some £200. Undoubtedly this work has been valuable if quoted only in terms of the data we can furnish to our colleagues of the Survey on their arrival here. But there is another and more important aspect concerning research by University workers: that concerns the desirability of maintaining independent and critical research workers who are not tied to one integrated programme for the whole country. Among our scientific colleagues of the Survey, this comment would probably seem superfluous, but one is not quite so sure that the point is thoroughly appreciated by those who control the funds for research over the whole country.

A SHORT ACCOUNT OF THE GEOLOGY

Despite the numerous papers by the authors cited and the appearance of maps showing the volcanic cones in some detail prepared by Hochstetter, Shrewsbury (1892, perhaps the earliest of Thomas's advanced students), and more recently Wong (1946) a really detailed map of all formations near the city has not yet been published, although it is now in preparation at the university; difficulties in mapping the Tertiary have presented one of the chief obstacles. Most descriptions of these strata near Auckland appeared before 1940 and require re-examination in the light of papers by Finlay and Marwick (1940, 1947). Only a thorough examination of the Foraminifera can serve to correlate many of the beds which, particularly in the lower part of the Tertiary, are thin and show marked facies variations. Bearing in mind that such information is not yet available, the following comments should be read as a brief and tentative summary of published correlations rather than as a geological description of the province. They may serve the student as a scheme of temporary pigeon-holes to be replaced in the future by some more authoritative classification based on the data of the present Survey. For more descriptive accounts, the reader is referred to Searle's "Geology of the Auckland District" (1948) and to a summary by Bartrum (1949) of the "Geology of Auckland City".

In the accompanying table (Table 1), the province, for convenience, is divided into five portions—North Auckland, South-west Auckland, Central Volcanic Region, Cape Colville Peninsula, and Auckland City. The information on which the table is based includes published work, work in the form of unpublished theses by students of the university, and information privately conveyed by research workers. Acknowledgement is made to these sources of information either in the text, in the table, or in the list of references. It is impossible to condense many of the details, particularly of unpublished work, into tables designed to cover such a large district in a few columns. The figures after formation names indicate thickness in thousands of feet. Where precise age correlations are possible, they result largely from the work of the Survey paleontologists. No attempt is made to discuss that portion of the province extending from the Bay of Plenty eastwards; geologically, much of the latter field is better treated as an extension of the Hawke's Bay-Poverty Bay portion.

The district around the city is given a separate status because in some respects it is a hinge point at which the geology appears to change and also because the region unites in fragmentary portions geological features better developed separately north and south of it.

The greywackes are the oldest rocks of the province. The fossiliferous strata on the West Coast are certainly Jurassic and contain in places boulders of igneous and metamorphic rocks derived from some ancient land lying, presumably, west of the present New Zealand (Macdonald, 1954). Several theses from Auckland students have added to the knowledge of this Mesozoic stratigraphy (Gilbert, 1921; Purser, 1952; Dow, 1955; Grant-Mackie, 1957; Player, 1958; Clarke ,1959). The more sheared and jointed greywackes and argillites, which are marked as *undifferentiated* Jurassic-Permian on the geological map of New Zealand (N.Z. Geol. Surv., 1958) and which stretch with interruptions from Cambridge to North Cape, have not yielded much information, as fossils are rare in them; near Morrinsville, Bartrum found (1957b) *Inoceramus galoi* and, by further collecting, the Jurassic age has been confirmed by Kear and Tolley (1957). More recently, a few more Jurassic fossils have been found by students at Kawau Island, Ponui Island, and the Hunua Ranges not far from the city (Milligan, 1959a). The most complete studies of these rocks near Auckland are those of Halcrow (1956), Brothers (1956), and Hopgood (1956), the work of the latter authors indicating that the rocks have suffered severe folding, probably with superposed axial trends, a tectonic history more complex than that of the fossiliferous strata south-west of Auckland city.

Farther north, at Whangaroa, the undifferentiated greywackes have yielded fusilinids (Hornibrook, 1951), for the first time in New Zealand, and corals of Permian age (Leed, 1951). In the Cape Colville Peninsula, where Jurassic fossils have been collected (Fraser and Adams, 1907; Kear, 1955), one may also suspect that the greywackes are partly of Permian age. Similar greywackes with Jurassic fossils have also been found in the Bay of Plenty (Fleming, 1953; Paltridge, 1958), so that it appears that a large part of the undifferentiated Jurassic-Permian is certainly Jurassic.

The only strata now acepted as definitely Cretaceous are the very folded, sheared, and in some places fossiliferous sandstones and mudstones of the Otamatea Formation. Probably slightly later than these would seem to be the associated tholeiites, dolerites, basalts, andesites, and gabbros of the Whirinaki Formation of Mason (1953) and Harrington (1944).

Unconformably overlying the Otamatea beds, and over-stepping on the folded greywackes, is the Onerahi Formation ascribed by the earlier bulletins to a Cretaceous age, but now relegated by Survey paleontologists to the Eocene. The complete absence of Otamatea beds south of Orewa would seem to indicate either a long phase of Cretaceous emergence throughout this western part of the North Island or very conconsiderable Tertiary erosion.

That the Onerahi beds, which do not now outcrop south of Silverdale, once had a greater southern extent is proved by fragments of Onerahi sediments in the Manukau breccias, as well as among some of the inclusions contained in volcanic rocks near Auckland city and as far south as the Hunuas (Healy, 1935). A deep drill-hole recently completed south of the Manukau Harbour penetrated both Onerahi and possibly Cretaceous rocks of the Otamatea Formation (D. Kear, pers. comm.).

According to the condensed summary published by the Survey (Marwick, 1948b), p. 24), the Onerahi Formation, of calcareous sands, hydraulic limestones, greensands, and siltstones varying locally in lithology, includes strata of Dannevirke, Arnold, and Landon Series; and the Whangarei limestone and associated strata must be coeval with part of the Onerahi beds, for they are also attributed to a Landon age. Near Silverdale, serpentinites apparently intruded into the Onerahi sediments contain inclusions of diorite, dolerite, and amphibole (Bartrum, 1939, 1944, 1948).

It seems likely that these rocks have been brought up by the intruded serpentine from some deeper layers in the crust, and the amphibole schists do recall rather similar rock fragments, found in Pleistocene basalts at St. Heliers, Auckland, and recently described by Searle (1959b). Here, again, there may be suggestions of the elusive ancient land already mentioned, although Searle prefers to regard the rocks at St. Heliers as products of retrogressive metamorphism of post-Cretaceous basic or ultrabasic intrusions.

Early Tertiary terrestrial conditions are indicated by the coal seams of the Waikato district, which, according to Suggate and Couper (1952), were deposited during the later part of Arnold time, almost directly on the greywacke basement, and it seems also likely that the seams on the flanks of the Hunuas are approximately of the same age. The rapidly varying facies of the Eocene and Lower Oligocene throughout the province suggest shallow-water shelf sedimentation broken by periods of emergence following a longer emergence that occurred during Cretaceous time. The former extent of such beds is not known, but near the city all Cretaceous, Eocene, and Lower Oligocene beds are absent and the Waitemata Formation of Miocene age rests directly on the greywacke basement.

The precise age of the various limestone inliers at the base of the Tertiary on the flanks of the Hunua Range, as at Papakura (Laws, 1931), long remained uncertain, but they are now assigned to Otaian (Kear, 1957) on the evidence of microfaunas; similar limestones occur at Tuakau (Battey, 1949).

According to Finlay's original determinations of stage position, north of Port Waikato the Pareora Series (Later Oligocene) was regarded as entirely absent, as in most parts of the North Island, and this break was supposed to be particularly conspicuous in the record of the Auckland province. However, Mr N. de B. Hornibrook, from the evidence of microfossils collected by Schofield (1958a) and by the writer, considers that the Waitemata Formation of Waitemata Harbour is certainly in part of Pareora attribution(upper Oligocene) as well as of Miocene age (pers. comm.). Barron (1956) has also obtained Otaian faunas from the Waitemata Formation near Bream Tail. This is just one of the several complications involved in mapping the Waitemata Formation.

It is likely that some folding and certain that some erosion must have preceded the deposition of the Waitemata sandstones, for in some places they rest directly on the greywackes and elsewhere on the Otamatea or on the Onerahi sediments; pebbles derived from the Onerahi Formation have been found in the Waitemata beds at the Manukau Harbour. The Waitemata Formation consists of well-banded marine sandstones and fine siltstones, with subordinate but abundant beds of mudstones. In these beds, worm-trails and fragments of wood are the most abundant organic traces; microfaunas collected at several places fix the age of formation as partly Altonian and only very recently (see above) have Otaian faunas been identified. To what extent faunas originally identified as Altonian have now been relegated to Otaian the writer cannot say, and it would be premature to discuss the point here. Scattered molluscan faunas appear to confirm the Altonian age, although locally as at Orakei Bay (Hochstetter, 1864; Hutton, 1885), there are richly fossiliferous bands (de Courcey Clarke, 1905; Powell and Bartrum, 1929; Powell, 1938; Dell, 1950; and Laws, see below). The formation name has been applied to similar strata intermittently from Hokianga to Tuakau on the West Coast, but the facies is replaced east of Hokianga at Mangonui by lignite beds and sands with fossil coconuts of Altonian age (McDonald, 1951).

Locally, conglomerates occur in the Waitemata Series, of which the most important is that known as the Albany conglomerate (Bartrum, 1920) containing abundant cobbles and boulders (maximum diameter 1½ ft) of granodiorite, dioritic gneiss, andesite, and dolerite, as well as greywacke and chert. Again, it is customary to postulate a source in some ancient land now sunk beneath the Tasman Sea. Elsewhere, similar outcrops occur in the Waitemata Formation and locally reach a thickness of 700 ft, with boulders 8 ft in diameter (Ferrar, 1934; Bartrum, 1924; Turner and Bartrum, 1929; R. H. Clark, 1948). Unfortunately, the exact stratigraphic position of these conglomerates in relation to the base of the formation is unknown. Smaller concentrations of similar pebbles are also found at localities on the shores of the Manukau Harbour. East of Auckland city, where the Waitemata sandstones rest on an irregular surface of greywacke, often surrounding stack-like masses of greywacke, fossils have been found at Cape Rodney, Kawau Island, Motutapu, Motuihe, and Maraetai. Some of the molluscan faunas at these places are very similar to those of localities farther north—Pakurangi Point, near Batley (Laws, 1939, 1941, 1944) and Hokianga (Harrington, 1944; Laws, 1947, 1948; Milligan, 1959).

Curiously enough, although it is one of the earliest mapped formations in New Zealand, stratigraphic details concerning the Waitemata sandstones are still obscure. Hochstetter noted a certain band of andesitic grit—the Parnell Grit—and later workers have found that outcrops of a similar band, usually 10 to 20 ft thick, are common at various places on the Waitemata and Manukau harbours. As the Waitemata sandstones show locally steep dips separated by tracts of more gently dipping strata, sporadic but seldom accurate attempts have been made to map the outcropping bands of grit as representing one horizon and thus build up a stratigraphic and structural picture of the Waitemata Formation near the city. Hector had hopes that this grit would serve as a marker between Cretaceo-Tertiary and Tertiary beds, and most Survey men passing through Auckland had instructions to spend some time on the Parnell Grit. Thus in 1871 Hutton wrote on the grit, to be followed by Cox in 1881 and 1882a and 1882b, by Park (1886a), and McKay (1844, 1888). Mulgan (1902) and Fox (1902), early students of geology under Thomas, presented lengthy and opposing papers on the stratigraphic position of these exposures of andesitic debris, Mulgan maintaining that all of them represented the same horizon, Fox assuming that there were at least two horizons of mineral and rock fragments of different provenance, one source being the western volcanic chain which yielded Manukau breccias, the other an eastern chain near the present Cape Colville Peninsula.

Admitting that there may be several bands of grit, it still seems likely that the Parnell Grit of Parnell Point is repeated by folding several times and is locally a horizon marker. Further stratigraphic precision in the Waitemata sandstones demands a very detailed building up of a general succession from such local marker beds. If all the outcrops of grit do prove to belong to the same horizon, it would follow that the Waitemata Formation from Maraetai to Titirangi is essentially flat lying and affected by minor undulations of amplitude not exceeding some 150 ft. The use of the formation name over a region stretching from Auckland to Hokianga without more precise stratigraphic definition tends to retard progress.

The origin of the folds affecting the Waitemata sandstones is another problem requiring further examination. Turner and Bartrum (1929) believed some of the most conspicuous folds at Takapuna to be caused by compression of the earth's crust. Workers in Europe have, over the past twenty years, increasingly stressed the formation of folds by sliding of water-logged sediments on the sea floor, and such a cause would explain the very pertinent observation made by Park in 1887 that upper layers of sediment were folded although lower layers lay quite flat.. Kuenen (1950), who visited Auckland, ascribed, with good reason, many of the folds in the Waitemata sandstones, especially those at Takapuna, to such subaqueous slumping.

If all the folds have been thus produced, structural mapping may give little information concerning the disposition of the formation as a major unit. On the other hand, the minor slides and slumpings may be due to larger fold or fault movements or to a regional tilt affecting the land as a whole, and the examination of minor folds may be a clue to the disposition of much larger structures.

The Manukau breccias, containing abundant and commonly huge blocks of andesite, were deposited in marine waters and result from great explosive activity in Altonian time. It is clear from evidence cited by Pohlen (1934), Searle (1944), and Brothers (1948, 1954a) that these andesitic agglomerates are inter-stratified with sediments ascribed to the Waitemata Formation, but the evidence is hardly sufficient to indicate whether the agglomerates are contemporaneous with the bulk of the Waitemata sediments that are exposed in the Waitemata Harbour or with only the upper part of those. Several faunas have been found in the Manukau breccias (Powell, 1935) at Motutara, Dreamlands, and Sharp's Bush, and some would appear to have a *late* Altonian aspect (A. W. B. Powell, pers. comm.). Lavas of andesitic composition occur as gigantic pillows contained within the Manukau breccias at Muriwai (Bartrum, 1930c). Even more remarkable pillow lavas of this age have been found by Brothers (1954c) at Tinopai on the Kaipara Harbour and described in detail by Arlidge (1955).

Other volcanic breccias and lavas of Altonian age are quite extensive and were early reported farther north near Whangaroa by Bell and Clarke (1909) as the Wairakau breccias. The hypersthene andesites near Mangatawhiri described by Battey (1949) may be also coeval. It is quite likely that the lower part of the "First Period" Volcanics of Cape Colville Peninsula is of similar age.

South of Tuakau on the West Coast, facies changes in the Tertiary appear on which officers of the Survey have been working recently (Kear, 1957). Strata of Pareora Series, unknown farther north, the Mahoenui Formation and Waikawau Group, appear between the Te Kuiti limestone and Mokau beds (Gilbert, 1921; Purser, 1952). The Mokau Formation is probably a deeper water and thicker facies of the Altonian, and the Mohakatina is probably also a facies variant of the Altonian. Proceedings towards Taranaki, the Tertiary sequence becomes progressively more complete and the Taranaki Series and all stages of the Wanganui Series appear. On the other hand, at Kaawa Creek (near Port Waikato), the whole of the Southland and Taranaki Series is absent, and strata of Opoitian, Waitotaran, and Nukumaruan stages (Gilbert, 1921; Bartrum and Powell, 1928; Laws, 1936a and 1936b, 1940; Purser, 1952; Kear, 1957) rest unconformably on Pareora strata, whilst near Auckland, at Otahuhu, and below sea-level, Opoitian beds found in a well (Marwick, 1948a; Laws, 1950) are likely to rest directly on Waitemata sandstones. Other Pliocene shell beds have been found in drilling south of the Manukau Harbour.

The evidence of such localities as Kaawa Creek, where all the Miocene is missing is consistent with the opinion that near Auckland post-depositional faulting, and some degree of folding, affected the Miocene

Waitemata beds, probably rather late in Miocene time. This view is independently based on the existence, near the city, of Tertiary rocks of very similar facies separating the typical Waitemata sandstones from underlying greywackes at Whitford (Firth, 1930), near Papakura (Hay's Creek and Bell Creek) (Laws, 1931), and at Otau, some five miles south-east of Clevedon (Brown, 1942). These places are all at different altitudes, the last-named being approximately 800 ft higher than the basal beds of Whitford. It is more reasonable to attribute part of the faulting giving uplift of the Hunua greywackes to post-Altonian faulting than to assume the coincidental overlap of *similar* facies at different heights on to an irregular and previously upfaulted landmass. The steeper dips of Miocene and earlier strata near the fault-line scarps amply support this view. Beyond the city, similar evidence is known at many localities. It is likely that any very late Miocene and Pliocene beds were deposited on a land of marked relief.

Taking the province as a whole, it has long been evident that the dominant structural trend, presumably of great faults and folds formed during the Tertiary, swings from north near Port Waikato to northwest in the North Auckland Peninsula. At right-angles to this swinging arcuate trend are many faults of throw which, in places, probably exceeds 1,000 ft. The age of the period when this structural trend was "roughed out" probably dates back to the late Miocene. This break between the Miocene and Pliocene is quite widespread in New Zealand, and appears to coincide with a similar break in western Europe. One may venture to suggest that, on closer analysis, more sharp breaks are likely to be found between the major sub-systems of the Tertiary in New Zealand as well as in Europe. Although the major earth movements seem to have ceased in Auckland before Pliocene time, some faults must have been active much later, for they dislocate volcanics such as the rhyolitic rocks of Cape Colville Peninsula of probable Pleistocene age. The faultings forming the Hauraki graben must be placed among such late movements (Bartrum, 1927, 1930b).

The fossiliferous Opoitian beds found in the well at Otahuhu are very similar to the Pliocene beds found on the surface (Day, 1948) and in drill-holes (Schofield, 1958a) south of Manukau Harbour; these are shell beds containing faunas, mostly of Waitotaran age, whose habitat lay at depths somewhere between five and ten fathoms below sea-level. The present heights of the shell beds in relation to sea-level range from − 375 ft to + 50 ft, and Schofield (1958a) is of the opinion that the beds could have been deposited during eustatic rises of sea-level and that differences of elevation do not imply any differential earth movement subsequent to their deposition.

Besides these shell beds, there are, in many parts of the province, un-dated sands, presumed on no clear evidence to be of Pliocene age, and one cannot yet base any precise deductions on these. However, it does seem evident that from late Pliocene times onwards traces of eustatic movements have survived in North Auckland and Auckland districts, although block faulting may locally complicate the record.

Certain of these sands and silts, possibly late Pliocene, and certainly Pleistocene and Recent in age, are related to extensive high flat surfaces at various levels. These, according to the early work of Turner and Bartrum (1929), occur not far from the city at heights of approximately 550 to 560 ft, 350 ft, 220 to 250 ft, and 100 to 120 ft. Later than the formation of these were two phases of sea-level at least 150 ft below that of the present day separated by a phase when sea-level was approximately 40 to 60 ft above the present height, and culminating in an extensive drowning almost certainly to be correlated with the Fandrian transgression. Many coastal tracts near the city and in the North Auckland Peninsula give extensive indications of these presumably eustatic evidences, particularly the digitate pattern produced by the final valley drowning. Beyond Port Waikato, this comparatively simple set of surfaces has not been so clearly identified.

Other writers who have touched generally on these surfaces in their writings are Henderson (1924) and Gage (1953). Those who have done more detailed work near Auckland include Firth (1930), Searle (1944, 1948), Day (1948), Clark (1948), and Brothers (1954b), who, after tracing similar levels in the Kaipara Harbour, has discussed other work of this kind and prepared tentative correlations of these surfaces with those presumed by Zenuer to be of eustatic origin in Europe. Searle has more recently undertaken exhaustive study of sea-level changes, and part of his work is incorporated in recent papers on the geomorphic evolution of the isthmus (1956, 1958b, 1959a).

The great sheets of volcanic rock found in the north Auckland peninsula are mostly, with some exceptions already mentioned or placed in Table 1, of Pliocene age. Growing evidence suggests that centres of activity moved during the Pliocene and Pleistocene (Fleming and Steiner, 1951), so that very similar volcanic rocks are not necessarily coeval. It seems probable that most of the volcanics of North Auckland were extruded on an extensive land surface. Although, as indicated, many of the faults and folds are likely to have been active in post-Pliocene time, it is not clear to what extent faulting also immediatly preceded the volcanism tentatively dated as Pliocene. The earlier volcanic rocks of the Central Volcanic region are now placed as early Pleistocene; those of the Cape Colville region were erupted in part during the Pliocene and probably also during Miocene time (Hayter, 1953; Couper, 1953). The volcanic cones of North Auckland are, however, usually younger than the extensive basalt flows and some are probably coeval with the cones of Auckland city; similarly, scattered scoria cones in the southern part of the province (Olson, 1950) must be of very late date. The cones and tuff rings of Auckland city rest on Pleistocene silts and lignites, and one of the more interesting aspects of Searle's results is his reconstruction of the old pre-volcanic topography. It would appear that the lava flows were emplaced usually in very deep valleys carved in Waitemata sandstones and that, as a result of post-volcanic erosion, the present topography commonly shows a complete inversion of relief, the hard basalts standing out at the present day as more resistant ridges than the surrounding country of

TABLE 1.

EUROPEAN DIVISIONS	NEW ZEALAND DIVISIONS	N Z STAGES (FINLAY & MARWICK, 1947)	CAPE COLVILLE PEN & GT BARRIER ISLAND	CENTRAL VOLCANIC REGION	SOUTH-WEST OF AUCKLAND PROVINCE		NEAR AUCKLAND CITY				
					Huntly - Raglan - Te Kuiti - Mokau	Port Waikato - Mercer	Bombay Hunua	[illegible]	[illegible]	[illegible]	[illegible]
RECENT				Ash showers basaltic and rhyolitic ash basalt Waitahanui volc breccias Haparangi rhyolites acid-andesitic cones		pumice silts sands and congloms.	Basalts ? Pumice silts and gravel	Harbour drowning = Flandrian	Drowning of Harbours Basalts, olivine basalts	Basalts and andesites	
PLEISTOCENE	Wanganui Series	Castlecliffian	'Third Period' Volcanics, rhyolites	Ignimbrites	Ss, silt, ms Shell lst, ss, silt. Arg ss, and shell lst Rangitikei f. 5·	Old dune sands ? Basalt flows ? Kaawa Ck f ?		Basaltic cones and tuff rings Pumice silts sands and lignites High level erosion surfaces	Kaihu Sands ? ?	Kaihu Sands ? ?	
PLIOCENE		Nukumaruan,						Pliocene shell beds Day 1948, Schofield 1958	[illegible]		
		Waitotaran							[illegible]		
		Opoitian	'Second Period' Volcanics, andesite & breccias & tuffs	Marine sediments below Ruapehu (Fleming and Steiner, 1951)	Ss and shell beds	Kaawa Ck f shell sands	Probably present below alluvials etc	Otahuhu f Shell, sd			
MIOCENE	Taranaki Series	Kapitean	Plant fossils (Hayter, 1953; Couper, 1953)		Mohakatina f Arg ss, ms, & andesite tuff 3·					[illegible]	[illegible]
		Tongaporutuan	? 'First Period' Volcanics, andesites								
	Southland Series	Waiauan			Mohakatina f. Ms						
		Lillburnian	?		Mokau f Ms and arg ss facies passage ?						
		Clifdenian									
		Altonian					Waitemata f Ss & silt w tuff like Parnell Grit (on Hunuas; D A Brown, 1942) no and break ?	Interstrat w Waitemata f {cgl w ff on and E coast	[illegible]	[illegible]	[illegible]
OLIGOCENE	Pareora Series	Awamoan			Mahoenui f Ms 5–1·	Waikawau Group (Kear, 1957)	Ss w cgl bands Papakura lst				
		Hutchinsonian									
		Otaian									
	Landon Series	Waitakian	Torehine f, ms ss lst (Brothers & Mason 1954 Kear 1955)		Te Kuiti lst ·1–·5	Te Kuiti lst			[illegible]	[illegible]	
		Duntroonian									
		Whaingaroan			Whaingaroa f g'sd & calc ms 1 Coal measures 1 (Suggate & Couper, 1952)	Whaingaroa f poor thin coals nr Mercer and ms.	Marine ss, coals and shales, marine sh, coarse cgl		[illegible]	[illegible]	[illegible]
EOCENE	Arnold Series	Runangan	Carb ss ?						[illegible]	[illegible]	[illegible]
		Kaiatan									
		Bortonian									
	Dannevirke Series	Porangan									
		Heretaungan									
		Mangaorapan									
PALEOCENE		Waipawan									
UPPER CRETACEOUS	Mata Series	Wangaloan							[illegible]	[illegible]	
		Teurian									
		Piripauan									
MID CRETACEOUS	Clarence Series				Neocomian present ?	Neocomian plants				[illegible]	
JURASSIC TRIASSIC	Hokonui System		Manaia Hill f, gke, arg cgl Inoceramus, belemnites Moehau f ?	Gke of Kaimanawa R, fossils unknown	Most stages present near coast gke and arg abundant fossils 28	Most stages present abundant fossils gke and arg 28	Undiff gke and arg. Rare Jurassic fossils	[illegible]	[illegible]	[illegible]	
PERMIAN			Tokatea Hill gke, (?) tuffs & rhyolites		?	Probably at depth				[illegible]	

NOTE Thicknesses, where estimated are given in units of a thousand feet (e g ·5 means 500 ft)

An oblique line indicates that formations at each end of line are known to occur in direct stratigraphic contact

Waitemata sandstone. Some of these small éruptive centres were evidently earlier than others, and their order of appearance can be found by relating the eruptive rocks to the sequence of geomorphic developments. Black Reef, a flow of basalt connected with the extinct Mt. Eden volcano, extends well into the Waitemata Harbour, and the position suggests that this flow took place at the latest before the Flandrian transgression. On the other hand, the symmetrical Rangitoto Island, which shows that ash was erupted from Rangitoto volcano about 750 interrupted by modern shore-cliffing is quite a new volcano, as shown by the latest stratigraphic and archeological work of Brothers and Golson (1959), supported by ^{14}C dating of Fergusson and Rafter (1959), which shows that ash was erupted from aRngitoto volcano about 750 years ago. From his botanical studies on the island of Rangitoto, Dr L. H. Milliner would expect to find evidence of some even later eruption, probably as late as 200 years ago, since he considers the vegetation on the island to be remarkably new.

There appear to be two main types of volcanoes in the Auckland city district (Searle, 1948). One is the maar, a wide depression surrounded by a low tuff-ring, formed by sudden volcanic paroxysm throwing out only fine ejecta with little or no lava. Such explosions are by many writers attributed to sudden ingress of sea water to underground masses of hot gas or lava. This type of explosion may be followed by the building of volcanic cones, usually within the tuff-rings. These cones, which are more conspicuous, consist essentially of masses of basalt scoria and lapilli roughly stratified and dipping steeply and radially from the vents. These are the products of fire-fountaining of liquid lava, and associated with scoriaceous material are sometimes found sheets of vesicular basalts. The latter, on closer examination, would seem to have been extruded through the outer and the lower slopes of the cone in a fashion similar to that of many of the modern basalt flows of Paricutin in Mexico. It was formerly considered likely that these basalt flows in the Auckland district had come from the summits. Besides these larger phenomena of volcanism, there are many smaller features of great interest excellently developed in the vicinity of the Auckland city. Lava tunnels have been described by Bartrum (1930a) and Searle (1949), who have noted the tumuli on the surface of the lava fields near Penrose. Bartrum (1930a) and Searle (1949) have described the effects of gas fluxion on the walls of these lava tunnels forming an iridescent surface on the lava, and they have also described drip stalactites formed as a result of such gas fluxing.

Among the more beautifully displayed phenomena are the replacements of tree trunks by basalt described by Bartrum (1947), and especially a very unusual occurrence of charred wood partly replaced in such fashion as to accentuate the medullary rays in the form of thin walls of rock. Searle (1958a) has described in basalts that surround similar moulds the production of native iron as the result of reducing reaction of carbon or hydrocarbons with the previously crystallized magnetite of lavas. The metamorphism of sediments entangled in the lava has also been described by Searle (1950).

The whole volcanic field of Auckland is replete with evidences of all the phenomena to be seen in modern basaltic cones, and, although these are now extinct or dormant, one has the compensating advantage of being able to see the inner structures exposed by excavations.

It would be beyond the scope of this work to attempt any elaborate reconstructions of the paleogeography of the Auckland province and, indeed, the data for much of the province are still lacking. Despite recent insistence on the ambiguities of lithologic mapping, strata of certain stages or series seem to maintain their general lithologic character extensively. Although it would be hazardous to map them solely on a lithologic basis, it is equally hazardous to map entirely on faunal correlations. The upper part of the Arnold Series is occupied by coal formations, and in many parts of the province beds of especially calcareous nature, like the Te Kuiti limestone, were deposited very extensively in the Landon epoch, a feature of the Landon in several other parts of New Zealand already noted by Macpherson (1945). The existence of such widespread shallow shelf seas in New Zealand tends to be ignored in general accounts of sedimentation in New Zealand, and in this respect the "lumping" of long periods of time as characterized by geosynclinal conditions, so common in generalized accounts of sedimentation, tends to obscure the discussion of significant changes in sedimentation.

It has sometimes been said that the North Auckland Peninsula constituted a Cretaceous and Tertiary geosyncline. For Tertiary time, this is doubtful on present evidence, unless the term is used to cover a period when strata of only moderate thickness were deposited with many erosion breaks, diastems, and many calcareous horizons. At present, there is much to favour Bartrum's old view that the Waitemata sediments may be of deltaic origin, and, if so, we may imagine these strata as passing laterally to the deeper water geosynclinal sediments of the Mokau Formation, deposited in a region where we have good evidence of much more continuous and thicker Tertiary marine sedimentation. Most of the Auckland province appears to have become land earlier than other coastal parts of the North Island, probably at the end of Miocene time; Pliocene and post-Pliocene faulting has been less intense than in other parts of the country and connected with this early history is Auckland's present comparative seismic stability (Eiby, 1955).

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STRATIGRAPHY OF THE LOWER PART OF THE MAITAI GROUP, NELSON

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Summary

The lower part of the Maitai Group, previously referred to as the limestone of Wooded Peak by Hochstetter (1864), the Maitai Limestone by McKay (1878), and the Rangitoto Formation by Wellman (1957), is subdivided into five formations. The contact with the Te Anau rocks and ultramafics to the east is locally faulted.

INTRODUCTION

The Permian Maitai Group of Nelson lies above ultramafics and Te Anau breccias and spilites to the east, and adjoins Triassic beds and "Brook Street" (Te Anau) volcanic rocks to the west. Limestone is developed at the base of the Maitai Group, and extends along most of the eastern margin. This limestone was first described by Hochstetter (1864, p. 226) as the "limestone of Wooded Peak". Hochstetter (1864, p. 227) named the overlying strata the "Maitai Slates", and Davis (1870) referred the limestone to the same group; McKay (1878) called the limestone the Maitai Limestone. Wellman (1957) referred briefly to the limestone as the Rangitoto Formation, a name taken from D'Urville Island, where limestone is developed at the same horizon.

Little work on the "Wooded Peak" or "Maitai Limestone" in the Nelson area has been published since the early reports by Hochstetter (1864), Davis (1870), and McKay (1878, 1879), and no large-scale map of the beds has ever been presented. Because of this lack of detailed study, it has been possible to gain only an approximate idea of the contact between the Maitai beds and the underlying volcanic rocks, serpentine, and dunite. It was shown by Hochstetter (1864, p. 226), followed by Davis (1870), McKay (1878, 1879), and Wellman (1948, 1952), that the limestone lies above Te Anau basalt and breccia, or ultramafics, extending in the Nelson area from north of Maitai River south-west for most of the eighteen miles to Little Ben Mountain.

It is absent, as mapped by Bell, Clarke, and Marshall (1911), between the north branch and south branch of the Maitai River, and also between the Serpentine River and Little Ben. The limestone varies considerably in thickness from place to place. The lithology also apparently varies. Two limestones separated by green beds occur at Wooded Peak (McKay, 1878) and at a headwater tributary of the Roding River (Davis, 1870), whereas only one major band without green beds is found elsewhere. Possibly the variations in thickness and in lithology are due to non-sequence, or perhaps to facies changes, as implied by McKay (1879), who suggested that the limestone becomes progressively thinner and less pure to the south. Other possible explanations are that faulting has occurred, or that some beds have been assimilated by the ultramafics to the east. No worker had mapped the beds in sufficient detail to discover which is the most likely explanation.

This paper is concerned with the stratigraphy of Hochstetter's limestone below the Maitai slates. By subdividing the "limestone" into formations, it is shown that the apparent variation in thickness and lithology of the beds is due in part to faulting and in part to facies. The boundary between the Maitai and Te Anau in Nelson is complex, and not as conformable in detail as was considered by McKay (1879, p. 110) or Grindley (1958).

Eight days were spent by the writer on reconnaissance field work in the lower part of the Maitai Group near Nelson, with visits to Rai Saddle, the Motueka River, and the Eglinton River.

STRATIGRAPHY

In the Nelson area, the lower part of the Maitai Group comprises two major units, the upper one sandstone and siltstone, the lower one chiefly limestone. Throughout the limestone are beds of green, more or less calcareous sandstone, and green sandy limestone. The proportion of green beds varies in different parts of the sequence, enabling the limestone to be further subdivided. These subdivisions are based on subtle differenences, and probably do not hold far to the north or south.

The most complete sections of the limestone in the Nelson area are exposed by the Dun Mountain Tramway, the two large unnamed tributaries of Roding River to the south of Wooded Peak, and United and Champion creeks. Of these the best section is offered by the Roding tributary south of Wooded Peak, and this is proposed as type section. The following formations are recognized, and named from neighbouring landmarks.

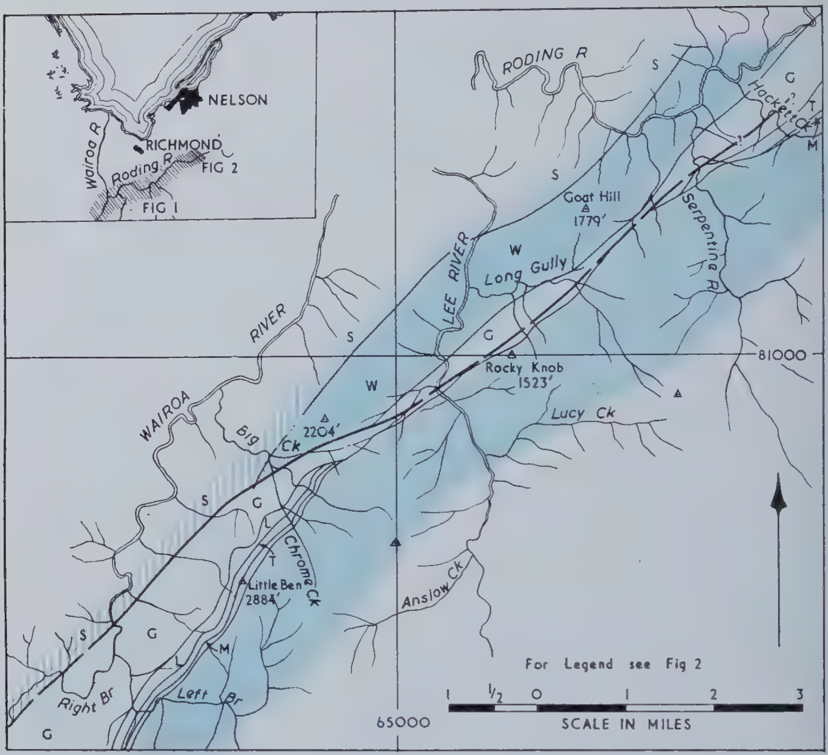

FIG. 1.—Map showing the stratigraphy of Hochstetter's Wooded Peak limestone, in the lower part of the Maitai Group of Nelson. The Greville, Waiua, and Stephens formations in the higher part of the Maitai Group were proposed by Wellman (1957). The name "Stephens", taken from Cape Stephens, was misspelt "Stevens" in 1957.

Wooded Peak Limestone

The name Wooded Peak Limestone is chosen because Hochstetter (1864) had referred to the limestone as the "limestone of Wooded Peak", where it is well exposed on the crest of the peak, and on the southern slopes along the Dun Mountain Tramway.

The Wooded Peak Limestone apparently lies at the base of the Maitai Group, and comprises about 120 ft of muddy light-to-dark grey limestone in beds usually 6 to 8 in. thick. Samples from the limestone failed to show any trace of dolomite, although Hochstetter (1864, p. 226) stated that limestone near Croixelles Harbour to the north is somewhat dolomitic. Nests of pyrites are present, and prisms of *Atomodesma* common. Beds of green coloured sandstone and grit 1 to 6 inches thick, and 2 or 3 ft apart, are associated with the limestone.

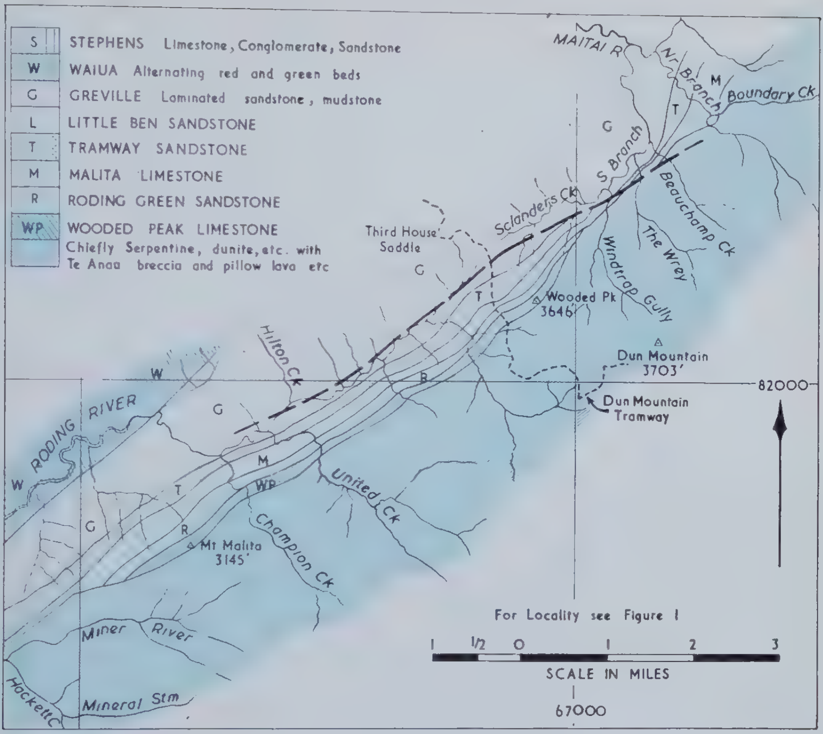

FIG. 2.—Stratigraphy of the Wooded Peak limestone of Hochstetter, in the lower part of the Maitai Group of Nelson.

The green beds are made up chiefly of fragments of igneous rock, including spilite, dolerite, and granophyre, with fragments of greywacke and argillite.

Roding Green Sandstone

Immediately west of the Wooded Peak Limestone lies about 50 ft of green, slightly calcareous sandy mudstone and muddy sandstone, rarely gritty, in beds usually 1 in. or 2 in. thick, with rare massive beds up to 4 ft thick. Locally the sandstone grades up into blue or grey calcareous mudstone. The sandstone, named from the Roding River, was recognized at Wooded Peak and immediately south in the tributary of the upper Roding River by McKay (1878) and Davis (1870). Calcareous lenses and veins of quartz are common, and fragments of *Atomodesma*, 2 or 3 sq. in. are present.

Malita Limestone (Fig. 3)

Named from Mt Malita, this limestone is about 450 ft thick. Two members are present. The lower member, 250 ft thick, is predominantly alternating thin pink and thicker green limestone in layers ½ in. thick, grouped in larger units 6 in. to 12 in. thick. In some places current bedding is visible in the slightly coarser green layers, and some green layers grade up into the pink, so that top and bottom can be discerned. Pull-apart cracks are common in the pink layers.

The upper member comprises dark grey or light pink limestone like that of the Wooded Peak Limestone, with prisms of *Atomodesma*, and worm tubes.

Beds of green sandstone and calcareous mudstone are scattered throughout, but are much less common than in the underlying member.

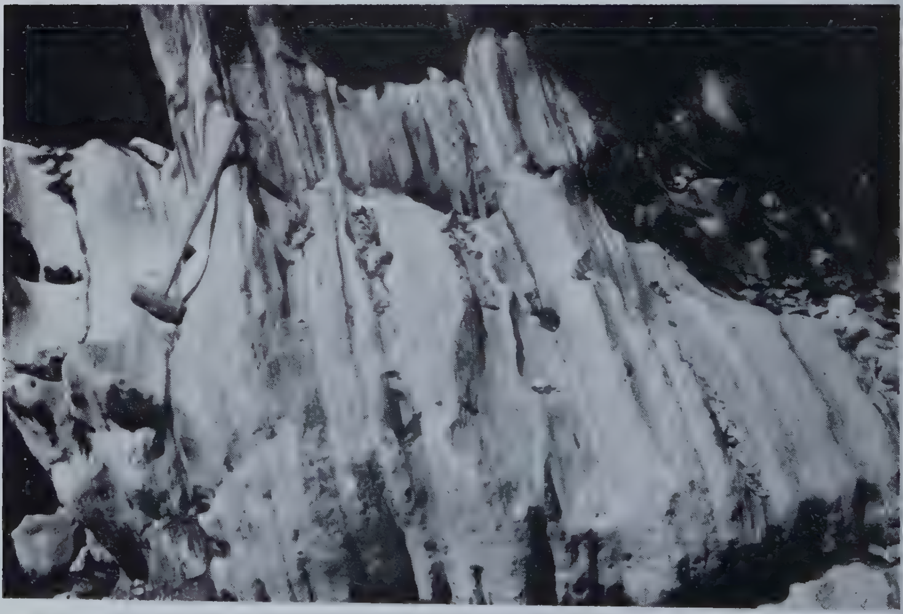

FIG. 3.—The pink and green member of the Maitai Limestone, in the upper tributary of the Roding River, immediately south of Wooded Peak. The layering is faintly visible but is obscured by partial bleaching of the limestone.

Tramway Sandstone

The Tramway Sandstone is named from the Dun Mountain Tramway, where McKay first collected the "Dun Mountain *Inoceramus*" in abundance. It comprises about 500 ft of fine sandstone and siltstone in beds 4 in. to 8 in. thick. Single valves of *Atomodesma (Aphanaia) trechmanni* Marwick (see Waterhouse, 1959) are common along the bedding planes, wherever the formation is exposed, although the beds along the tramway now seem to have been collected exhaustively. Worm tubes are locally abundant.

Above lies the Greville Formation, named by Wellman (1957).

LATERAL VARIATION

Little Ben Sandstone

In the type and nearby sections the Tramway Sandstone is separated from the overlying finely laminated Greville Formation by 10 to 20 ft of barren calcareous grey-green sandstone. This is so thin that it is conveniently mapped with the Tramway Sandstone. South of Lee River, the Tramway Sandstone becomes thinner, and the overlying sandstone apparently thickens into a coarse green massive unfossiliferous sandstone, described by McKay (1878) on Little Ben. The sandstone is well exposed at the right branch of the Wairoa River, proposed as type section. Here the green sandstone is 150 ft thick.

Similar massive green sandstone underlies typical Greville beds in the Motueka gorge, 12 miles south-west of Wairoa River. The sandstone exposed by the gorge is at least 500 ft thick; the base was not observed. Moreover, the sandstone is very similar to the massive green sandstone that comprises the bulk of the Howden Formation in the Eglinton Valley (Grindley, 1958). Here the sandstones lie above a basal muddy limestone, and below the Greville-like laminated beds of Grindley's Tapara Formation. Otherwise there is little lateral variation in the formations between the Maitai and Roding rivers. The Roding Green Sandstone becomes finer and more calcareous to the south, and includes much limestone in the United and Champion streams. The upper part of the Malita Limestone contains thin sandy layers and has large shell fragments in Hackett Creek and farther south. The statement by McKay (1879) that the limestone thins progressively from 2,000 ft at the Maitai River to 1,000 ft at Wooded Peak and still more to the south, is incorrect. His earlier and more conservative estimates of thicknesses in 1878 are more accurate.

FAULT WITHIN THE FORMATIONS

A fault is present at the South Branch of the Maitai River, above the junction with Sclanders Creek. Here the Tramway Sandstone and the upper member of the Maitai Limestone are missing. The Greville beds lie adjacent to the pink and green limestone typical of the lower mmber of the Malita Limestone. To the south-west this fault passes into the Greville beds, and is well exposed along the valley of the upper

Roding River as a low angle reverse fault, dipping at 40° to the east, with a narrow crush zone an inch or two across. Although not so shown on the map, the fault probably continues south within the Greville Formation to Big Creek, where it apparently cuts out the Waiua Formation. In this area, however, the position of the Waiua beds needs to be confirmed by further mapping. Small strike and dip-slip faults are also present in the formations, and are especially common in the overlying Greville beds.

CONTACT WITH THE ROCKS TO THE WEST

Generally, the contact between the limestone and the underlying Te Anau volcanics and ultramafics appears to be approximately conformable. The Maitai Group lies to the west of these rocks from D'Urville Island to Top House in Nelson, and from the Olivine Range to Mossburn in northern Southland and Western Otago. But in detail the contact is not conformable. Previously this has been obscured by the failure to recognize divisions within the "Maitai Limestone".

The sequence north of Wooded Peak as far as Cook Strait is generally incomplete, due to faulting or non-deposition, as assimilation by the ultramafics. Thus, at the serpentine quarry at the head of the Whangamoa River, eight miles north of the Maitai River, beds with *Atomodesma* lie next to the ultramafic and volcanic rocks. No limestone is present. Limestone must appear within a mile or two to the south, for the North Branch of the Maitai River exposes a full sequence of the Malita Limestone. The pink and green member passes out just south of the North Branch. A little farther south the upper member of the Malita Limestone lies next to the ultramafics. The beds come in again on the northern ridge of Wooded Peak.

For the five miles between Wooded Peak and Mt Malita all formations are represented. The basal Wooded Peak Limestone rests usually on agglomerate and breccia of Te Anau volcanic rocks. Five miles to the south, at Hackett Creek, the upper member of the Malita Limestone lies next to the Te Anau, and the lower formations are not visible.

A mile and a half to the south-west at Serpentine River, the upper member of the Malita Limestone is missing, and the Tramway Sandstone lies next to the Te Anau. Davis (1870) mapped limestone in this river valley, but none has been found by Bell, Clarke, and Marshall (1911), or by the writer. It seems likely that Davis mistook massive outcrops of green cherty rock for limestone. This rock has a cream-coloured surface and looks like limestone from a distance. It occurs within the ultramafic complex, and is akin to though not so hard or so altered as the "baked argillites" that are associated with the ultramafics and volcanics, as reported by Hochstetter (1864), Jones (1939), Keyes (1958), and other authors. A mile farther south-west the Tramway Sandstone is also missing, the ultramafics lying next to a thin strip of weathered beds, tentatively assigned to the Greville Formation. Within a few yards are the characteristic red and green Waiua beds; the Greville Formation has been reduced considerably in thickness.

The Tramway Sandstone and upper member of the Malita Limestone reappear some 5 miles to the south-west in the major northern tributary of Chrome Creek, and have been traced for 3 miles to the left branch of the Wairoa River. The contact has not been examined by the writer farther south-west, except in the Eglinton Valley .

Thus, the contact between the Te Anau and Maitai is gently sinuous. Locally the limestone is unconformable, and mapping suggests that, in addition, the limestone is locally separated from the Te Anau rocks and ultramafics south of the Maitai River, and south of Hackett Creek. It is not known whether the absence of the Wooded Peak Limestone and Roding Green Sandstone north of Big Creek and north of the Maitai River is due to faulting or to non-deposition. A faulted contact is consistent with interpretations of Park (1887), Turner (1930, 1934), Hutton (1937), and Kingma (1959), who suggested that the ultramafics have been intruded along faults. Indeed, Hochstetter (1864, p. 218) clearly considered that the ultramafics had been intruded, and recorded a "friction breccia" of blocks of limestone, slate, and serpentine between the ultramafics and (Malita) limestone at the Wrey Stream; Davis (1870) also mentioned this "friction breccia". However, the breccia could be related to the minor fault that enters the Greville Formation farther south. It has not been examined by the writer.

In spite of widespread support for an intrusive origin for the ultramafics, it has not yet been proved whether the ultramafics were emplaced before or after the deposition of the Maitai Group. Usually the ultramafics do not visibly intrude the limestone, on a small scale at least, apart from possible intrusions at Boundary Creek. Evidence for intrusion has previously been adduced from the presence of "baked" argillites, but these seem as a rule to be within the Te Anau rocks rather than the Maitai beds. Although lime-garnet grossularite occurs along the boundary, supposedly formed by contact metamorphism of igneous rocks with the limestone, according to Marshall (1907, p. 321) and Finlayson (1909, p. 355). Marshall, Bell, and Clarke (1911, p. 31) showed that the same rock, termed rodingite, is also present at some distance from the limestone, within the ultramafics. Nevertheless, the occurrence of the grossularite is a suggestive one, and might repay further inquiry.

It is interesting to note that the ultramafics closely approach or lie at the boundary of the Maitai beds where the Maitai formations are incomplete or missing. This suggests ingestion of the beds by the ultramafics.

Generally it is considered that the ultramafics were intruded in the Cretaceous. To the writer emplacement in the Permian is much more likely, for the close association of ultramafics and volcanics points to a genetic relationship rather than a coincidental one. Grindley (1958) has put forward an alternative to the intrusive origin for the ultramafics as presented by Hochstetter and many other authors. He considered that the ultramafics were extruded in deep sea and were followed conformably by the Te Anau volcanics, which in turn were overlain by limestone. This hypothesis is still feasible, since the likely faults between the limestone and Te Anau volcanics and ultramafics cannot yet be definitely related to the intrusion of the ultramafics.

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DR HOCHSTETTER IN NELSON

(EXTRACTS FROM THE DIARY OF SIR DAVID MONRO, 1813-17)

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(Received for publication, 23 June 1959)

Summary

The diary of Dr (later Sir) David Monro, from February to November 1859, records a leading Nelson settler's part in early mining activities in Nelson and his contacts with Hochstetter during his visit to report on the geology and mineral resources of the young province.

Introduction

David Monro (1813–77) came from an Edinburgh family that had produced three generations of professors of anatomy and surgery at Edinburgh University. He attended medical schools in Paris, Berlin, and Vienna before emigrating to New Zealand, arriving in Nelson in 1842. In 1844, he explored Otago with Tuckett. He took up land in the Waitaki and at Culverden, as well as near his home town of Nelson. He was made a magistrate in 1842, was appointed to the Council of New Munster in 1849, was elected to the Nelson Provincial Council in 1853, and was nearly continuously in Parliament from 1853 to 1873, serving as Speaker for some time. His connection with New Zealand geology was cemented for life by his daughter's marriage in 1868 to Dr (later Sir) James Hector, Director of the Colonial Museum and Geological Survey of New Zealand. He was knighted in 1866 and retired from public life in 1873. Further biographical details are given by Scholefield (1940, pp. 91-2).

Monro's unpublished diaries for 1859 record the hopes and disappointments of local enthusiasts who were at that time supporting the attempts to win copper and chrome at Dun Mountin, coal at Jenkins Hill (Nelson) and Pakawau, and gold in the Aorere. They also provide perhaps the only available contemporary account of the two-month visit of Hochstetter, accompanied by his friend and assistant, Julius Haast.

Apart from minor changes in punctuation, the extracts quoted below are direct transcriptions from Monro's diary. Many sentences dealing with family, social, and business matters, of no direct interest to geologists, have been omitted, but some matters are included for the sake of continuity and to provide the background for the narrative of a pioneer settler whose versatile interests included horse-breeding, education, and sheep-farming, as well as mining, medicine, and politics.

N.Z. J. Geol. Geophys. 2 : 954-63.

FEBRUARY 1859

26, Saturday.—I . . . went to the Dun Mountain Co^{s} office. Despatches have been received, ordering the Com^{tee} to pay off all the men & discontinue every item of expenditure. Mr Hacket's* salary is not to be paid him.

28, Monday.—At 11 went to a Meet^{g} of the Com^{tee} of the D.M. Co. At it till ½ p. 1.

MARCH 1859

9, Wednesday.—I accompanied by Aleck went up to Jenkins† coal mine. Picked up Kerr the banker on the way & made him come with us. When we had been there a short time Jenkins came. We inspected the ground and the diff^{t} works. The strike of the strata is S.S.E. The dip, an angle of about 40°. Both the shafts that have been sunk are in such a place as to miss the seams. But the stratification does not seem continuous.

22, Tuesday.—After dinner attended the meeting of shareholders in Jenkins coal. Voted into the chair. A good deal of discussion. Resolved to suspend all operations & get Dr Hochstetter's opinion.

23, Wednesday.—After dinner went to attend a meeting of Com^{tee} of Lit^{y} Instit.‡ which did not come off.

APRIL 1859

4, Monday.—Took Georgie§ to school this mor^{g}. Her first time.

5, Tuesday.—Drove down at 2 o'clock picked up Curtis and drove out to the coal mine at Jenkins. I find the direction of Jenkins drive not to be due East & West, as he represented to me, the consequence of which is the stratification is almost due north and south, instead of N.W. & S.E. as I had fancied. After spending about a couple of hours at the mine, we drove to town.

6, Wednesday.— . . . Had some talk with Wells** about the Pakawau mine††

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*T. W. Hacket, mining engineer, came to Nelson as director of the Dun Mountain Company, and took an active interest in the economic geology of Nelson and Westland.

†Jenkins' coal mine was described by Hochstetter (1864, p. 235; 1867, p. 82).

‡The Nelson Literary and Scientific Institution, organized by the founders of Nelson in 1841, later the Nelson Institute. Monro had been secretary *pro tempore* in 1842, president in 1843. See Brereton, 1948.

§Maria Georgiana Monro on 30 December 1868 married Dr (later Sir) James Hector. See Haast, 1948, pp. 511-12.

**William Wells arrived in 1850, farmed at Wakapuaka, was a member of the Provincial Council (1855–61) and M.H.R. for Nelson and Wairau.

††Pakawau Coalfield was described by Hochstetter, 1864, pp. 321-3.

12, Tuesday.—Went to old Wrey's lecture in the evening.*

18, Monday.— . . . To the office of the Dun Mountain Co. where we had a Com^{tee} Meet^{g} & looked over the despatches just arrived. They appear to be in a better humour.

MAY 1959

2, Monday.— . . . Called at Hackets . . . to see him about the Pakawau business and some letters he is writing to the Directors.

30, Monday.—Wrote a letter to the editor of the Colonist about the Pakawau coal comp^{y} in answer to Mr Parker's remarks at Motueka. . . . Did some gossiping in the town, chiefly about gold prospects.†

31, Tuesday.—At ½ p. 2, Meeting of Gold-wash^{g} Company. I was voted into the Chair. We all paid down £10 per share & provisionally formed the Company, Levien, Curtis & Moore Directors, Kerr Treasurer, Scaife Secretary.

JUNE 1859

4, Saturday.—Went down with letters . . . & then went to a meeting of the local Com^{tee} of the Dun Mountain Min^{g} Co. At it the greater part of the day dictating a letter to the Directors.

15, Wednesday.—Went down in the forenoon to meet Elliott, Travers & Curtis about this gold-leasing business. We had a consultation at Curtis', and resolved to get Moore to make an application for a lease.

JULY 1859

2, Saturday.—Went to the Dun Mount. Co^{s} Office. At 12 returned to the Resid. Magistr. office. . . . Returned again to the Dun Mount. office & was there all day with Wells & Hacket, talking over matters. Dictated a letter to :the Directors which Wells and I signed. Hacket gave me one or two Photographic views of Nelson. They are rather dark but artistical.

4, Monday.—Saw Moore about the gold leasing business & hurried it on.

11, Monday.—Had talk with Moore & others about gold lease. Agreed to withdraw the orig^{l} application & put in another.

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*W. L. Wrey lectured to the Institute on "Geology and Mining". He was the driving force behind the Dun Mountain project and fell out with Hacket (Haast, 1948, p. 39). The Triassic brachiopod *Spirigera wreyi* Suess, discovered by Hochstetter, was named in his honour.

†In the Aorere Valley, where gold was discovered in 1857.

13, Wednesday.—Meeting of gold mining Co. at 4. Had Dobson's report before us.* The extent of cutting is more than I had anticipated.

18, Monday.—Heard this mor^g the portentous news of war hav^g broken out between France, Sardinia & Austria.†

20, Wednesday.—Went down . . . to the Dun Mountain office which I found locked.

22, Friday.—Went with Wells to the Dun Mountain Co^s office to see the last despatches. Nothing new . . . looked over the plans of the ground for gold washing by Dobson.

23, Saturday.—Called at Curtis and had some talk with him about our gold washing. We shall now have to give up the idea of laying dry the bed of the Aorere River.

26, Tuesday.—Wrote to Kenneth McKenzie . . . and wrote also to Clifford about the Dun Mountain affairs.

29, Friday.—At 7, I went down to Mr Heppel's‡ to talk over the list of philosophical apparatus for the Institute. This point settled, we had some mulled wine and tobacco, and a pleasant chat and argument.

AUGUST 1859

2, Tuesday.—Hacket called & I arranged with him that we sh^d meet in the evening to write letters to the Dun Mountain Co. Directors. We had a great deal of talk & agreed to a letter which is to be sent.

4, Thursday.—In the afternoon met Major Richm^d who has returned.§ Had a chat with him. Went with him to call on Dr Hochstetter at the Trafalgar. Saw also there Mr Haast, both of them very pleasant men. Their plans are not yet matured. Richmond walked up home with me.

5, Friday.— . . . Went to Curtis to get his brother's address. Had some talk there about the movements of the savan^s. Wells came & told me they were going to take a walk up Brook St Valley. I accompanied them to the old coal seam. Wells & Travers** with us & David Graham. On the way back they came into my house & had a glass of wine. I gave Hochstetter one or two specimens of Jenkins' coal.

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*Edward Dobson (1816–1908) was provincial engineer for Canterbury and his son (Sir) Arthur Dobson, a lad of 18 at this time, also became a surveyor and engineer. Brereton (1948, p. 35) states that A. Dobson lectured to the Institute in 1859.

†The war between Piedmont (assisted by France) and Austria, a stage in the unification of Italy.

‡George Heppel, M.A. of Cambridge, headmaster of Nelson College, 1859–61.

§Major Matthew Richmond (1801–87) held important military and civil positions, and was Police Superintendent of the Southern Division of New Zealand. Hochstetter and Haast arrived by the Lord Ashley on August 3.

**W. L. T. Travers (1819-1903), a lawyer with a passionate interest in natural science, was M.H.R. for Waimea and District Judge.

6, Saturday.—Finished my letters this mor^{g} & posted them, Sir Cha. Clifford, K. McKenzie . . . my brother James, W. J. Hamilton Esq. . . . with several copies of Hochstetter's lecture* one for Mr Hamilton, one for Clifford: one for G. Skene, one for Jim, one for Weld. Put Beau in the trap and drove up to Jenkins to meet the scientific party. Sent the trap on to the Turf with Charles & met Hochstetter and party near Cundy's. Went on to the coal mine. Had luncheon & went in to the shaft, seeing all that we could. Went round next by the Poor Man's Valley to the limestone quarry.† The strata there appear to rise tow^{ds} the S.E. Went down to the Turf, where we had some beer & drove home, I taking old Wrey in my conveyance.

7, Sunday.—Went to church in the forenoon. After church I had some talk with Mr Connell about the man . . . at Richm^{d} who has been found in a well with his throat cut. Called on Dr Hochstetter afterwards. He goes tomorrow morning to Massacre Bay via the Croixelles & Current Basin.

18, Thursday.—Met Gibbs & had some gold talk and we went in to Curtis', where we had some further parley upon the same subject.

25, Thursday.—Went down by appoint^{t} at 12 to see Hochstetter. He consulted me about various matters: about the laying the stone: the dinner‡ &cc, and I promised, if he w^{d} write his speech in German & send it to me, I w^{d} translate it for him. Called at Curtis' & had talk with them. Had a talk also with Elliott. Saw Haast at work with his Moa bones.§

26, Friday.—Translating Hochstetter's speech into English for him. Went down with it about 12, saw him & had some talk. Went to Adams** to tell him that Hochstetter wishes him to say a few introductory words. Walked home & went down to the town with Ninna & Georgie. The foundation stone ceremony going on: oddfellows, masons, &cc in all their glory. The stone of the Nelson Institute was next laid, Hochstetter's speech going off very well. Home in the afternoon: pruning gooseberry bushes. Rough called in the evening to say the Sup^{t}. is going with Hochstetter tomorrow to the boulder bank. I therefore declined going.††

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*The "Lecture on the Geology of the Province of Auckland", delivered to the Members of the Auckland Mechanics' Institute on 24 June, 1859.

†The limestone quarry at Stoke, described by Hochstetter, 1864, pp. 235-6.

‡Hochstetter was to lay the foundation-stone for the second Nelson Institute building, on a site provided by the Government (Brereton, 1948, pp. 34–6), after the stone had been laid for new Government buildings. For an account of the public dinner at which Monro took the chair, see below and Haast, 1948, p. 29.

§Collected from limestone caves at Collingwood (Hochstetter, 1864, pp. 242-8).

**Henry Adams, a prominent Nelson lawyer and Provincial Councillor.

††The Superintendent was J. P. Robinson, whose election Monro twice contested. *Austrofusus robinsoni* (Zittel) was named in his honour.

29, Monday.—Down to the town at 9 to join Hochstetter & party for the Dun Mountain expedition. Wells & I rode: the rest of the party drove for 5 miles. At the foot of the hill we had luncheon & left our horses: we then had a beautiful walk through woods to the bottom of the steep ascent where the spurs of the hills are open & the country what is called Mineral. We got in just as it was getting dark, all right after a very pleasant day. In the evening, the Aurora Australis was very beautiful, tinging the Southern sky of a rich rosy hue, with paler rays shooting towards the zenith. Early in the morning it began to blow.

30, Tuesday.—A dismal looking morning: wind & rain & great masses of mist rolling up the glen below the cottages. After breakf^t^ it seemed rather better, so we went out to look at the Chrome mine, but the rain came on again with sleet & we got ourselves wet through. Returned to the cottages about 12. Old Wrey, Travers & Haast went off for town & shortly after they were gone, the rain came down in torrents. In the afternoon it moderated again & we all went out & examined the orig^{l} workings. Spent a pleasant enough evening chatting about various things.

31, Wednesday.—A beautiful morning. After breakf^{t} we went to see Sullivan's lode and 3 spots where they were working upon it. At young Hacket's place it looks more promising than elsewhere. Returning to the path we found old Wrey who had come up in the forenoon as he said he sh^{d}. We all went back to dinner & then went & ascended the Dun Mountain proper, from the summit of which we had a very fine view over the mountain range bounding the Wairau Valley on the west. Back about dusk. Spent a pleasant evening.

SEPTEMBER 1859

1, Thursday.—We went down to look at the Windtrap lode, old Wrey piloting. He took us down into some very awkward gullies. After examining the Windtrap, old Wrey left us disappearing in the woods. We went round by another path to see what was called a Conglomerate, but is rather a breccia of fragments of Serpentine. We then came to the limestone & crossing it got on to the vertical slates of the Maitai. At the stockyard we had some luncheon & walked into town by Bartlett's range, getting in about 5.

2, Friday.—I went down to town to see about the arrangements for the dinner. Saw the band and got for them "God save the Emperor" & "was ist des Deutschen Vaterland". Home. After luncheon occupied upon my speech. Went down about 5 & called on Hochstetter who wished to see me about his speech. I got him to modify it a little and to strike out a part in which he expressed a hope that Germany would triumph over France. Deputation came for us & we went to dinner. The material was very bad: but the dinner went off extremely well. The speaking better than usual. Kept it up till about ½ p. 12.

3, Saturday.—Writing out my speech for the newspaper & correcting Haast's. In the afternoon we drove round to say good-by to the Dashwoods and called upon the Richmonds. In the town saw Major Richmond & Andrew & scolded them well for not coming to the dinner.

4, Sunday.—In the evening Hochstetter and Haast called and I gave the former some specimens of Alpine plants with which he was delighted. Writing letters.

5, Monday.—Went down to town to post my letters. Gave Elliott a cheque for £4:9, being £1:6 for the dinner and £3:3 towards cost of Mandamus. At 3 we had a meeting of the gold Company & determined to make Washbourne a definite offer by which we find the money for bringing water into Golden Gully: he finds the engineering & superintendence & is to get one third of the water.

6, Tuesday.—Went down to accompany Hochstetter to Wakapuaka: but first called at the Examiner* Office & corrected proofs of the speeches. Rode after Hochstetter & overtook him at Wells', where we had some luncheon. Then on to the Black horse. Then to MacKay's where we had a glass of wine & walked along the beach to the steep bluffs which consist of Syenite & from which Hochstetter thinks that the stones of the Boulder Bank have been derived. Back to MacKay's about dusk. Dinner, tea & other entertainments in the evening. All the family very kind and hospitable.

7, Wednesday.—Mackay, Wells, Hacket, Hochstetter & myself rode up by Pearson's into the Happy Valley. We left our horses at Brown's stocky^{d} & went on foot up the valley. The formation appears similar to that of the Maitai Valley. Vertical slates which Hochstetter thinks belong to the Devonian period. About 2, we had a luncheon consisting of cold chicken pie, & champagne which MacKay had hospitably bro^{t} with him. Rode into Nelson, stopping once more at Wells' to look at the black slates there & breaking some in hopes of getting characteristic fossil remains, which however we could not find. Home about 5.

11, Sunday.—Mr Haast came in the evening & Capt. Rough, and we had a pleasant enough chat.

13, Tuesday.—Went to the Dun Mountain Co^{s} office to transact some business. Agreed to a letter to Dr Hochstetter asking him for an opinion on the mine. In the afternoon, we had a meeting of the Gold Mining Co. Washbourne has accepted our terms, and the work is commenced.

25, Sunday.—To church in the forenoon. Went down after service to see Hochstetter who has returned. Arranged with him that he is to come on Tuesday morning to my house to go to work at his lecture.

27, Tuesday.—Hochstetter came to breakf^{t}. After breakfast, we had the dining room to ourselves, and commenced with his lecture. Went on at till about ½ p. 1.

---

*Charles Elliot (1811-76) established and edited the *Nelson Examiner* in 1842; Provincial Councillor and M.H.R.

28, Wednesday.—About ½ p. 10, Hochstetter came and we worked the whole day at his lecture. At ½ p. 4 I walked down to Elliotts with him, and made arrangements about the printing of his lecture.

29, Thursday.—Hochstetter came after breakfast, and with about an hour's work we finished his lecture . . . In town in the afternoon. About 20 minutes past 6, we went down to the lecture, but were rather late. The chapel was already crowded and we could not get good seats. The lecture went off very well. Rather a wet walk home.

30, Friday.—A wet day. I went down to the Examiner Office and corrected the proof of the lecture. Dined at Adam's. Hochstetter, Haast, and Heppel were there. Dinner over, went to the Assembly first, accompanying the two Germans to the Hotel where we smoked a cigar. We had a very nice party, and I danced a good deal. Home about 3.

OCTOBER 1859

1, Saturday.—Breakf^{t} about ½ p. 9 . . . I saw Dr Hochstetter off today, went round to the steamer at 11, went on board and said good-by to him.

6, Thursday.— . . . Walked up with Sinclair. Capt. Blundell, Greenwood and Mr Haast at dinner . . .

16, Sunday.—Putting things in order for leaving tomorrow. After breakf^{t} I went down to see Wells & had a long talk with him about the Dun Mountain business. We went down to Hacket's, where we had another long talk.

17, Monday.—Up early, packed up and drove down to town . . . then drove round to the Albion wharf & went on board . . . anchored at Wellington about midnight.

18, Tuesday.—Went ashore about 8, a N. wester blowing. Went to Crawford's. Kindly received there & asked to stop with them. Went out with Crawford along the beach.*

29, Saturday.—Up about 7 . . . Got to the Hurunui about 12, the river running swiftly & a heavy body of water . . . & reached Culverdon about 4. Found Glengarry & Dodds there, a hospitable welcome & everything comfortable. Beautiful beds, clean & fragrant & slept like tops.

---

*James Coutts Crawford, Wellington pioneer and geologist. Monro's visit to Wellington was en route to Lyttelton and Christchurch to inspect his Culverden run, "Montrose", originally part of the immense Dashwood land claim, which he held jointly with Macdonnel and Dodds. Here, perhaps influenced by his recent contacts with Hochstetter, he made the geological observations reproduced as the final quotations from the diary. The Tertiary volcanics and limestones of Pahau district, which Monro was the first to recognize, have been described by Mason (1949). On the return journey, at Wellington (Dec. 1), Crawford, Haast, and Monro "walked up the Ngahauranga road and round by the Porirua road".

30, Sunday.—Breakf^{t} at 8. After breakf^{t} sauntered up the glen at the back of the house among the limestone rocks. The beds of limestone run N.E. & S.W. lying at an angle of about 25°. Between them are beds of vesicular trap rather thicker than the limestone. At one place the line of junction was plainly to be seen, the limestone covered with a thickness of many feet of a coarse sand or fine gravel of bits of trap with septa of lime running through it & fossil shells so tender that they cannot be removed without crumbling. The limestone abounds in shells. Returned to dinner & rested during the afternoon. In the evening read Caird's sermon the religion of common life.

NOVEMBER 1859

5, Saturday.—After breakf^{t} Dodds, Glengarry & I rode up the Pahau to see what sort of boundary it is to the Southern end of the run. The day intensely hot & bright. The Pahau enters the hills by a gorge with steep sides, generally wooded down to the water's edge, in some places grassy, in others walls of rock. It is extremely picturesque. Our only road was the bed of the river: but this was not unpleasant as the day was exceedingly warm and the varying views of the glen, the bright sky overhead and the play of light upon the young foliage formed one of the prettiest runs I have been in in this country. At the horse shoe, basalt comes to the surface & is seen in contact with the till or diluvium. At the point of junction the clay is of a bright red, either burnt of that colour, or else the basaltic matter has mixed with & stained it. Higher up on the left side of the stream ascending, there is a limestone cliff which rises to the East apparently broken off & tilted up. Beyond this, the rock consists of a volcanic breccia, angular fragments of basaltic rock being enclosed in a crumbling matrix of reddish colored basaltic detritus. We rode up the Pahau about 2 miles, till we were stopped by a deep pool with wall-like sides which we c^{d} not pass. Had luncheon by the side of the stream ascended the hills & crossed over to the Black Birch Gully. After a hot scramble, got on to the plain & rode home. On the way I had a delicious bathe in the Pahau.

ACKNOWLEDGEMENTS

Dr R. E. Wright St. Clair, Hamilton, generously made available the typed transcript he had carefully made from Sir David Monro's longhand diary for 1859, and the extracts are published by kind permission of Miss L. C. Monro, Palmerston North.

Information in the footnotes is in part taken from Scholefield (1940).

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CORRIGENDA

N.Z. J. Geol. Geophys. 1 : 637.

Table 1 (First column):

For Fe_2O_3 Read Al_2O_3
For Al_2O_3 Read Fe_2O_3

Ibid. 2 : 120-2.

Text under "Introduction" should read:

The McMurdo Sound region of South Victoria Land is an area of mountainous ranges that extend 60 miles inland to merge with the Antarctic plateau at approximately 8,000 ft. Four major glacier valleys cut through these ranges; the Ferrar to the south, the Taylor and the Wright in the centre, and the recently investigated Victoria Glacier* to the north (Fig. 1). Only the Ferrar Valley carries ice throughout its entire length, the others being partly ice free except for hanging cirque glaciers. The ice free valleys are commonly referred to as "dry valleys" and from air reconnaissance are known to cover some hundreds of square miles in South Victoria Land. During summer months dry valleys are relatively free of snow and ice except for isolated patches within cirques or on glacier shoulders. Lakes commonly occupy depressions in the floors of dry valleys. Shumsky (1957) has described Bunger's oasis, an ice free region in Australian Antarctic Territory (Long. 100° 50′, Lat. 66° 00′) similar to the dry valleys of South Victoria Land.

Ibid. 2 : 129 (2nd paragraph):

For "20° C" read "2° C"

Ibid. 2 : 131 (1st paragraph):

For "grey granite" read "pink granite".

Ibid. 2 : 252 (2nd last line):

For "the plotted analyses do not give a good indication of the extent of the"
Read "the plotted analyses do give a good indication of the extent of the"

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